MOTHER EARTH

A POPULAR ACCOUNT OF THE EARTH
IN THE LIGHT OF RECENT
KNOWLEDGE

by

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DEDICATED TO

PROFESSOR S. H. REYNOLDS, M.A., Sc.D., F.G.S., formerly Channing Wills Professor of Geology in the University of Bristol, who first taught me geology and so taught me to read something of the fascinating story of the rocks, an inexhaustible fund of instruction and pleasure.

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PREFACE

WE human beings live and move and have our being on that body whic we call the earth; our bodies are, literally, made of its dust; so far as w know we cannot leave it, this tiny sphere of stony matter hung in space Our minds may probe the depths of inter-stellar space, but our bodie are confined to earth, so surely it behoves us all to have some knowledge however slight, of the ball on whose outer surface we exist.

It is the purpose of these pages to give some simple informatio respecting the nature, origin and features of the earth. Scientific term have been avoided so far as is possible, in order that the book may b read with—it is hoped—pleasure and profit by those who have no acquaint ance with the sciences. Accuracy and the presentation of the most recen results of research have been aimed at, and if perchance at times the shaf has missed the target, the author, and none other, is to blame. Sinc some technical terms must inevitably creep in, a short glossary has bee added.

Several recent theories, as yet not available in popular form, are her presented in language which it is hoped will be understood by all, so tha the man in the street may know something of what scientists are thinkin of the earth that has been a subject of study since man began to think.

Sins of omission and commission undoubtedly there are, but may suc merits as this work possesses atone for those. To the many authors whos works and results have been drawn upon, the author tenders his sinceres thanks, and humbly begs their pardon if he has failed to interpret thei theories as fully and as clearly as they might wish. To help those wh may wish to pursue the various aspects touched on, a bibliography i given at the end of the book.

Cam, Glos. T. A. RYDER.

April, 1947.

CHAPTER I

THE EARTH—WHAT IT IS

THE earth is a sphere of matter moving in space—it is our home, the only world we know at first hand, and is, therefore, all important to us. Human beings, so far as their bodies are concerned, are "of the earth, earthy". Men have always been fascinated by this stony ball on which they live and have tried to find out more about it, what it is like, how big it is, what it is made of, how it was made, how old it is, what it is doing, and so on. It is the purpose of the following pages to present in a popular way some of the information that modern science has to give us concerning the earth, and to answer these questions so far as we can.

As we look at the sky either by day or by night, we see other objects which we call heavenly bodies—sun, moon, stars and planets. These objects have been of interest to man for long ages; in fact, astronomy (in its first form, astrology) is the oldest of all sciences. But so long as there were no instruments to aid men's vision, little could be learned of those "lights" that were to be seen in the sky. The sun and moon and stars moved round the sky in great circles, or at least appeared to do so, and for many thousands of years the earth was regarded as the centre of the universe. It was the revolutionary suggestion of Copernicus that destroyed that old belief, a suggestion that was adopted and set on secure foundations by Galileo.

The idea, however, was not really new, for many centuries before the days of Copernicus, Aristarchus (*d.* 230 B.C.) had suggested that the earth revolved round the sun, but his idea was not taken seriously at the time. Galileo and others taught, and we now know, that the apparent revolution of the sun and stars around the earth was an illusion, and that what really happened was that the earth was a spherical body revolving around the sun, which was the centre of a system of planets, and that the apparent revolution of the stars was due to the fact that the earth rotated on its axis.

People, not unnaturally, did not like the new idea, since it made the earth less important in the universe than it had been supposed to be, and because it seemed to contradict the accepted doctrinal teaching of the Church and of Aristotle—the great authority on material knowledge all through the Middle Ages. The universe, or at least the solar system, was seen to be heliocentric, not geocentric. This great change in outlook is what is termed the "Copernican Revolution".

We know now that the earth is literally one of the "children of the sun", and together with the other planets moves around the sun in an approximately elliptic orbit. The planets, together with the sun, form what is known as the Solar System, a group of bodies that are connected

by the force of gravity like all the other bodies in the universe, and they were all formed at about the same time from the same source, as is explained later.

There are nine major planets, only six of which, including the earth, can be seen with the naked eye*—these were the only ones known to the ancient world whose star-watchers gave to them the names of their deities. In order outwards from the sun, the planets are—Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto, the last of which was not discovered until 1930. These bodies are at varying mean distances from the sun (see table below) and are of varying size, and they all revolve in ellipses around a common focus, in periods of different duration. This time of revolution is called a year, so that the year varies in length on different planets.

Planet.	*Mean distance from sun in millions of miles.*	*Time of revolution in our years and days*	*Diameter in miles*
Mercury	36·0	88 days	3,008
Venus	67·3	225 ,,	7,600
Earth	93	1 year	7,927 (equatorial)
Mars	141·7	1 year 322 ,,	4,200
Jupiter	483·9	11 years 314 ,,	82,800 (polar)
Saturn	887 1	29 ,, 167 ,,	67,200 (polar)
Uranus	1787	84 ,, 7 ,,	30,900
Neptune	2797	164 ,, 280 ,,	33,000
Pluto†	3670	248 ,,	7,900 ?

NOTE.—A recent determination of the distance of the sun from the earth made by the Astronomer-Royal, Sir Harold Spencer Jones, gives the mean distance as 93,005,000 miles ± 9,000. This result is likely to remain as the most accurate for a long while to come.

Dimensions of the Earth

A glance at the above table will show that the earth is one of the babies of the Solar System, and that it is fairly near, as astronomical distances go, to its parent sun around which it revolves in the actual time of 365 days 6 hours 9 minutes 9·5 seconds. This latter time is termed a sidereal year and is the time taken by the sun to complete a revolution from some fixed point—a star—in its *apparent* orbit, back to the same point. It is the discrepancy between this period of time and an exact 365 days that brings the complications of leap-years into our calendar.

* Under favourable conditions Uranus is just visible to the unaided eye on a dark night, so it may be claimed that six planets, excluding the earth, are visible to the naked eye.

† The diameter of Pluto is doubtful.

The earth is a more or less spherical-shaped body, with a mean diameter of 7,913 miles, the equatorial diameter being 26 miles greater than the polar diameter—that is, there is a flattening of the earth at the poles and a bulging at the equator. This is the result of the centrifugal forces which tended to throw matter to the part which rotated more rapidly during those early stages of the earth's existence when it was still in a fluid condition. This polar flattening and equatorial bulging can be seen to an even more marked extent in the case of the planet Jupiter, which some believe has an external crust of ice; but the effect is due to the atmosphere of ammonia and methane, which bulges out in equatorial regions.

The equatorial circumference of the earth is 24,902 miles, and its surface area—196,950,000 square miles—includes 139,440,000 square miles of water and 57,510,000 square miles of land—that is, only about two-fifths of the surface is above mean sea-level. Although these figures seem large they are small in comparison with the dimensions of other heavenly bodies. For example, the mean diameter of the sun is 866,400 miles, and it is large enough to contain 1,305,000 earths.

Let us illustrate these figures in another way. If some imaginary giant could obtain the necessary number of spheres the size of the earth he could put them into a sphere the size of the sun at the rate of one a second for 15 days 2 hours and 30 minutes before he would have filled it. And the sun—a star—is of average size amongst the other members of the Galaxy, as our system of stars is called. Many stars are very much larger—for example, Betelgeuse and Rigel, two brilliant stars in the constellation of Orion, are, respectively, 25 million and 27 thousand times larger than the sun.

Although the sun is so much larger than the earth, its density is much less, being only 1·4 (water is 1), whereas the density of the earth is 5·517. The sun is thus only 332,000 times as heavy as the earth, its actual weight being 1994×10^{27} tons. This means that the force of gravity (the effect of which force varies directly with mass and inversely with the square of the radius of the body) is very much greater than that force is on earth.

The actual figures expressed in acceleration of falling bodies from rest are, for the earth 32 feet per second per second, and for the sun 896 feet per second per second. This means that an average man whose weight on earth would be 12 stones would on the sun whirl the pointer of a spring balance round to 330 stones, or just over two tons. The rigidity of the earth is twice that of steel, so that it acts as a solid body, although, as will be seen later, its interior is at such a high temperature that the material there is potentially, at any rate, molten, and when pressure on it—which keeps it solid—is locally removed, it will flow out on to the surface in the form of streams of lava. It must be remembered in this connection that the lava from volcanoes arises from the relief of pressure in comparatively shallow layers of the earth's crust.

Since, the earth was once much hotter than it is now, and is losing

heat with the passage of time, it is a contracting body. This means that its surface becomes wrinkled, much in the same way as does the skin of an apple as the inside shrinks with withering, which is mainly loss of water. These wrinkles on the face of Mother Earth are the mountains and ocean deeps, and although they seem very obvious to us, are in reality very small when compared with the size of the earth as a whole. The highest mountain is Mount Everest in the Himalayas, the top of which is 29,141 feet above sea-level, or just under six miles. The greatest oceanic depth yet recorded is the Swire Deep, off the Philippines, 34,430 feet. That is, the total vertical range of the surface of the earth is 64,571 feet, or just over 12 miles, but this is only about 0·154% of the earth's diameter.

The amount of irregularity can be illustrated in this way—the total range is roughly equivalent to that of 0·005 inches on the surface of a cricket-ball, quite inappreciable, and in fact much less than the dents often made in the surface of such a ball by bowlers with their finger-nails in order to get a better grip for spin-bowling.

Movements of the Earth—Rotation

Although we who dwell on the face of the earth feel nothing of the movements that the earth is making, yet it is in continual motion, and in fact its motion is very complicated. There is, first of all and most obvious in its effects, what is termed the diurnal rotation—that is, the rotation of the earth on its polar axis once in every 23 hours 56 minutes. This is the movement that results in the alternation of days and nights, as one part of the surface or another is presented to the sun. Of this movement—or, rather, of the axis on which it occurs—something will be said later. Since one complete axial rotation is made in approximately 24 hours, it follows that every place on the surface at the equator is moving through space at a velocity of 1,038 miles per hour, since the circumference at the equator is about 25,000 miles. At the poles the speed of rotation is nil; at intermediate points the speed is dependent on the latitude.

This spin is also the cause of the steady pulsation of the ocean tides, although the waves of water which moves as the tide is piled up by the gravitational attraction of the sun and moon. The direction of rotation is from west to east, therefore the sun rises in the east.

Another consequence of this rotation is that moving objects or matter become deflected to the right in the northern hemisphere and to the left in the southern hemisphere. This is well illustrated in the case of the great ocean currents and the trade winds. The North-East Trades, for example, start out as southward-blowing winds from the high-pressure atmospheric belt between latitudes 30–40° N., towards the equator, and if the earth were stationary they would continue to blow in the same direction; but

since it is rotating from west to east, these winds become deflected to the west and are therefore north-east winds. Similarly in the southern hemisphere, the winds blowing from the high-pressure belt become south-east winds.

Naturally, since different parts of the earth's surface move through different distances in the same time, the amount of deflection due to the spin will vary from latitude to latitude, being greatest at the equator. This spin also tends to throw matter towards the equator due to the centrifugal force it produces, and it was this tendency which caused the equatorial bulge, a piling-up of matter at that period of the earth's existence when the whole body was molten and the crustal layers were capable of motion.

Apparently, of course, it is the sun that appears to revolve round the earth, and not the earth round its axis; but the experimental proof that it is the spin of the earth that produces the regular alternation of days and nights was given by Foucault, with his celebrated pendulum experiment at the Pantheon, in Paris, in the year 1851. He suspended a pendulum consisting of a long fine wire supporting a heavy piece of metal, to the bottom of which was attached a fine pointer of which the end just cleared the floor, but which ploughed a path through a layer of sand thereon. The pendulum was set swinging, and as it rested on a needle-point at the top—the point of suspension—there was very little friction to cause it to slow down, so it ran down very slowly. It was started so that the pointer swung along a marked line on the floor, and as inertia keeps a pendulum swinging in the same plane, if there were no motion of the earth, and consequently of the Pantheon, it would have continued to swing along the same line. But this was found not to be the case, the direction of swing as indicated by the pointer markings in the sand changed, and this was observed after a short interval. The floor part of the earth was thus proved to have turned round the pendulum—in other words, the earth rotates once a day.

But there is yet another movement of the earth in connection with the spin—namely, what is called the precession of the equinoxes. A good illustration of this phenomenon is seen in the spinning-top, the axis of which describes a cone round a line drawn perpendicular to the plane on which the top is spinning. While the top is spinning the force of gravitation tends to tip the axis still more from the perpendicular; but by a well-known gyroscopic principle, which it is unnecessary to describe here, instead of the axis setting itself parallel to the plane on which the point of the top rests, the conical motion takes place. It will be noticed that the axis of the top does not move in an exact circle because a slight wobbling, or oscillation, is seen, and this increases as the top recedes more and more from the perpendicular, as it is "dying"—that is, as the rotatory movement originally imparted decreases. This last effect illustrates another phenomenon in the earth's motion known as *nutation* (from *nutare*=to nod).

Just as the axis of the top is inclined to the vertical, so is the earth's axis inclined at an angle of about $23\frac{1}{2}°$ to the perpendicular to the plane of the earth's orbit or ecliptic plane. If the earth were devoid of rotation the attractions of the sun and moon on the equatorial bulge would bring the equatorial plane into coincidence with the ecliptic plane—that is, the plane in which the earth revolves round the sun. This tendency is opposite to that of the spinning-top, but the principle is the same. Owing to the earth's rotation, however, precession takes place just as in the case of the top, but in the opposite direction, and the precessional motion of the earth's axis results in a conical movement of the axis westward along a line joining the poles of the ecliptic. A complete revolution takes place in about 26,000 years.

It is this movement of the polar axis that accounts for the fact that the sun at, let us say, the vernal equinox, does not appear in the same position against the background of the fixed stars as it did many centuries ago, and this fact has been made use of in the dating of ancient monuments, many of which were constructed as sun-worshipping temples, and whose avenues were lined up with the direction of the sun's rays at certain times of the day and year.

A further consequence of this movement of the axis is that a line produced from it into space will not always be directed to the same point; at the present day such a line does lead approximately to the Pole Star, but such was not always the case, nor will it always be so. To quote Hogben, in *Science for the Citizen*:

> "It is a fortunate historical circumstance that there does happen to be a bright star practically at this point in our own time (i.e. on the imaginary line mentioned.) There was also a bright star very near it when the calendar cultures of the Nile and Mesopotamia flourished. Between 2000 B.C. and about A.D. 1000 there was no very bright star near the pole (i.e. on this line produced). We might perhaps go so far as to say that the approach of Polaris to the celestial pole was the herald of the Great Navigations."

The orbit of the moon is inclined to the plane of the ecliptic at an angle of about 5°, and hence the inclination of her orbit to the ecliptic varies from $18\frac{1}{2}°$ to $28\frac{1}{2}°$ ($23\frac{1}{2}° \pm 5°$). This inclination is responsible for a slight variation in the precession of the equinoxes and gives rise to nutation. Although there are other causes for this phenomenon, the one just mentioned is the chief factor. Nutation is thus an effect consequent on the forces that produce precession not acting uniformly, so that the earth's pole traces out a wavy curve—that is, it "nods", instead of tracing out an exact circle.

An interesting result follows from the fact that the earth's axis is tilted at an angle of $66\frac{1}{2}°$ to the plane of the ecliptic. It is this tilt that makes the sun appear to move north and south of the geographical equator in summer and winter respectively. When we talk about the

"sun crossing the line" we mean that the sun is then vertically over the geographical equator. If there were no tilt and the earth's axis was always at right angles to the plane of the ecliptic, then the sun would always be vertically above the equator at noon; but when the direction of tilt is towards the sun at its maximum—summer solstice—then the sun is vertically above the Tropic of Cancer ($23\frac{1}{2}°$ N.) at noon, and similarly at our winter solstice it is above Tropic of Capricorn ($23\frac{1}{2}°$ S.).

This apparent movement of the sun north and south results in the movement of the heat-equator (belt of maximum heat) between $23\frac{1}{2}°$ N. and $23\frac{1}{2}°$ S. during each year; this in turn affects the distribution of temperature and pressure-belts (see Chapter IX) and causes the seasonal variations, as well as the midnight sun and other effects in the polar regions. For when either pole is turned towards the sun there will be no sunset in its neighbourhood, and when a polar region is tilted away from the sun there will be no sunlight.

Revolution of Earth

Not only is the earth rotating at a great speed and slowly wobbling as it does so, but it is revolving in a great elliptical orbit as it makes its annual journey round its parent sun, an ellipse with perihelion and aphelion distances approximately $91\frac{1}{2}$ and $94\frac{1}{2}$ millions of miles respectively. For the earth to travel round that vast path in one year it is necessary for it to maintain a speed of 66,000 miles an hour. It is this annual revolution, coupled with the fact that the earth's axis is tilted at $66\frac{1}{2}°$ to the plane in which it makes the revolution (that is, the axis always points in the same direction) that causes the seasonal changes that we experience on the earth.

Owing to the fact that the other planets also revolve round the sun in similar orbits—all approximately in the same plane as that of the earth—but at different distances and speeds, there is considerable variation in the distances between the planets. At one time, for example, Mars and the earth may be on the same side of the sun at the same time, whilst at another time they may be on opposite sides of it. It is this orbital movement of the planets (including the earth) round the sun that produces the effect exhibited by them of moving across the night sky in a direction similar to that taken by the sun across the day sky, whilst the "fixed stars" (those outside the Solar System) appear to move across the sky in curves which are parts of circles whose centre is the North Pole star. These effects can be seen by exposing a photographic film, with the camera-shutter open, to the night sky for several hours, when on development arcs of light will be seen on the resulting print; these represent the tracks of the stars during the time the plate was exposed. At certain times, however, the planets appear to have retrograde motions, an effect due to the combined orbital motions of the planets and the earth.

But that is not all, for just as the earth is a member of a family of similar bodies—the planets composing the Solar System—so the sun is a member of a much larger family, whose members are the stars. All the stars seen in the night sky, including those in the Milky Way, together with the many more revealed by the telescope and the camera, form a great cluster or group of stars, which is termed the Galactic System, Galaxy or Island Universe. This is estimated to contain 100,000 million stars.

There are other similar groups of stars—the extra-Galactic nebulæ—far out in space, but they are so distant from our own Galaxy that they appear in the night sky as patches or clouds of light, called nebulæ. Until comparatively recently even the most powerful telescopes could not enable astronomers to distinguish the individual stars composing the Galaxies, but in recent years it has been found possible to resolve some of them—that is, to pick out some of the individual stars in them. This is done by combining the telescope and the camera, and using special red-sensitive plates under exceptionally good atmospheric conditions. In this way some of the nearer Galaxies or nebulæ have been resolved; most of them show a few individual stars, the largest in the system, which glow with a white light. Within the last year or so two nebulæ in the region of the constellation Andromeda have been resolved and these show a number of faint red stars.

Great as are the distances between the stars of our Galaxy—the nearest star to our sun is 4·3 light-years away*—those distances are almost negligible when compared with the distances between the Galaxies, some of which are 500,000,000 light-years away. This means that the light from them that we now see left the Galaxy concerned long before the great forests that gave rise to the coal-seams of our coal-fields had developed.

The stars that form a Galaxy are grouped, in an elliptical or lens-shaped cluster, and when viewed from a certain direction appear as spirals. The globular clusters are some ten times smaller in linear dimensions than are the smallest elliptical nebulae. Our own Galaxy is lens-shaped or lozenge-shaped, and the Solar System is situated well out from the centre of the group. All the nebulae, our own included, are revolving, and it is as though the Galaxy were a huge currant cake with the currants representing the stars and the rest of the cake representing inter-stellar space. On rotating a cake, all the currants rotate around a common point without changing their relative positions, but this does not apply

* Astronomical distances are so vast that to express them in miles is merely to bewilder with noughts, so new units of measurements are used, the *light-year* is the distance that light would travel in a year, and since light travels at 186,000 miles per second, that represents 6,000,000,000,000 miles in one year, whilst the *parsec* is approximately equal to 3¼ light-years, or 19 million million miles.

to the stars in the Galaxy. Each star or system of stars has its own motion, just like the planets, and they revolve around the centre of gravity of the Galaxy. The sun makes a complete circuit every 250 million years, and so traces out a colossal circle in space in that time. As will be seen later (Chapter IV), the age of the earth is such that with the sun, it has made four such revolutions since it became a solid body.

From all the above it is clear that the earth has many and varied movements, but since there is no fixed and absolute point of reference in space, these movements can only be given individually as relative to the sun, or some other body, which, in its turn, is already moving in an equally complex manner. The question naturally suggests itself, why do we not feel the effects of such motion? When Aristarchus first suggested that the earth was not central but really revolved around the sun, his idea was rejected by Ptolemy of Alexandria on the ground that such a motion of the earth would produce such winds that everything would be blown off the surface. Ptolemy did not know that the atmosphere was part of the earth and partook in its movements through gravitational attraction holding it to the solid earth.

The answer to the question posed is that the movements are so even and continuous that there is no jarring or acceleration. The effect produced is somewhat similar to that of a smoothly running railway train, wherein the passengers scarcely feel any sensation of movement so long as there is no untoward acceleration or deceleration, and one does not look out at the passing landscape. Perhaps an even better parallel is gliding down a gently-flowing stream in a boat.

The railway train affords another analogy in this connection. We are cognisant of the effects of the earth's movements in the alternation of day and night and in the changes of the seasons, but the ancients explained those alternations on the theory that the sun revolved around the earth, and so far as the alternation of day and night is concerned, this view gives a satisfactory explanation of observed facts, since motion is relative. This is parallel to the passenger in a train in a station with another train standing alongside. The starting up of the second train gives the impression for a few moments that it is one's own train that is moving, but a glance out of the window on the platform side serves to prove which is actually moving. So is it with the earth's movements; we need a check on our ideas, reference to another datum, and this shows that we revolve around the sun. If, from any cause, any or all of those motions were to cease, then we should feel the effects, and very violently too—there would be a great and disastrous jar. But so long as the motions continue no effects other than those observable ones, that is, of the alternation of day and night, winter and summer, are apparent.

The speeds at which the earth is travelling may be astounding, but it is when we consider astronomical distances that the mind is really staggered. It has been stated above that the mean distance of the earth from the sun is 93 million miles, or, to put it in another way, it takes a ray of

light, travelling at the rate of 186,271 miles per second, about eight and one-third minutes to reach the earth from the sun.

The nearest star, that is a body similar to our sun, is *Proxima Centauri*, which is 286,000 times as far away as the sun, or four and one-third light-years distant, that is, it takes four and one-third years for light to travel from the star mentioned to the earth, and that is our nearest neighbour in space, other than those bodies which compose the Solar System!

But *Proxima Centauri* is very near compared with the other stars; there are constellations in the sky, visible to the naked eye, whose light (by which we know of their existence) left its source before William the Conqueror came to England, whilst the telescope and the camera have disclosed the existence of stars whose light has been travelling through space (at the rate of 186,000 miles per second) for tens of thousands of years before they have reached the earth: the nearest spiral nebula or other Galaxy is nearly a million light-years away.

It is consideration of such distances that gives us some idea of the immensity of the universe, and by contrast, the smallness of the Solar System, and even more so of the earth in it.

Land and Sea

There are several other features of the earth that need mentioning here. One of these is the remarkable proportion and distribution of land and sea on the earth's surface. Fifty-seven and a half million square miles of the surface are land, that is 29·22% of the whole, leaving 70·78%, or just under 139½ million square miles of water. A glance at a map of the world will show that the land is very unevenly distributed, the greater part of it lying in the northern hemisphere, but the peculiarities of distribution are even better seen on a globe if we imagine the world divided into two hemispheres with their poles situated in Brittany, and near New Zealand. It will then be seen that in the "northern" hemisphere, or "land hemisphere", there is concentrated 81% of the land of the surface, including North America, part of South America, Europe, Asia and Africa. The southern or "water hemisphere" contains Australia, the southern part of South America, Antarctica and many small islands.

Another interesting feature easily spotted on a world map is that all the continents, with the exception of Australia, taper to the south, and so far as the northern hemisphere is concerned they all radiate out from a central Arctic sea. It only requires a lowering in the level of the sea by 100 fathoms (600 feet) to result in the emergence of land which would entirely encircle the north polar sea with but two straits connecting it with the North Atlantic Ocean, the one between Greenland and Iceland and the other between Iceland and northern Norway. Greenland itself would be joined to the mainland of North America, as would the islands

that lie to the north of that continent, whilst the Bering Strait would disappear and there would be a land connection between America and Asia. (This state of affairs did once exist as is shown by the presence of animals of Asiatic origin in North America.) In other words, the northern continental shelves of America and Eurasia enclose a circular polar sea whose boundary is roughly defined by latitude 80° N.

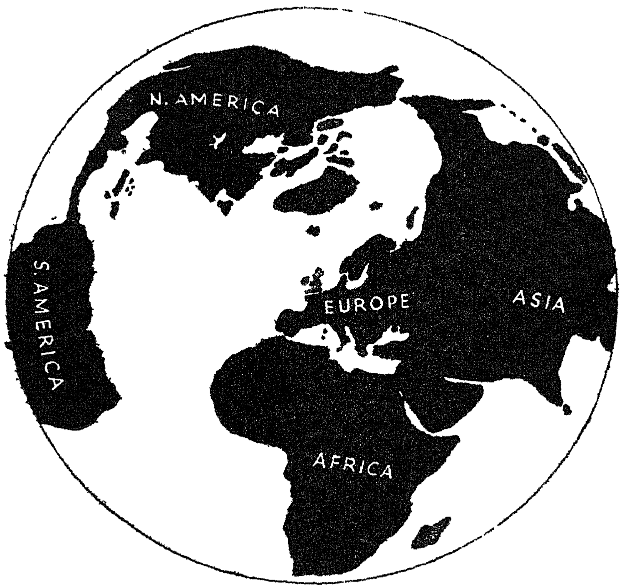

FIG 1. LAND HEMISPHERE

By far the larger part of the land surface of the world lies within a hemisphere of which the approximate centre is the British Isles.

On the other hand, the southern Pole is situated almost in the centre of a land mass, Antarctica, whose boundary is practically coincident with the Antarctic Circle. The site of the South Pole is about 9,000 feet above sea-level. In the southern hemisphere, Australia does fit to a certain extent into the pattern of tapering continents, for its continental shelf, on which stands the island of Tasmania, extends some little way south of the main mass as shown on ordinary maps. There is a submarine ridge —of maximum depth 1,000 fathoms—extending still farther south from this shelf and linking up with Antarctica.

Many ingenious theories have been put forward to account for the above facts but none of them is satisfactory—the origin of the continents still remains a geological mystery.

The Earth as a Magnet.

Another interesting feature of the earth is that it acts as though it were a gigantic magnet. The fact that the compass needle points to the north was formerly attributed to the attraction of the Pole Star, but Gilbert, in 1600, showed by experiments with ordinary compasses and with magnetic needles suspended horizontally (able to swing in a vertical plane) or dip-needles, that it was the earth that attracted the needles. The magnetic compass does not point to the geographical north but several degrees away from it, the amount of declination or variation as this divergence is called varied at different places and times. Lines joining places where the magnetic declination is the same are called isogonic lines and when plotted on a map or globe they intersect at the magnetic poles. The change of declination with time is due to the fact the situation of the magnetic poles changes, for example, the north magnetic Pole fixed by Sir John Ross as being in Boothia Felix, some thousand miles from the North Pole, in 1831, is now situated in the Sverdrup Island, some two to three hundred miles to the north-west of the old site and about 1,500 miles from the geographical Pole. The magnetic declination for London is about 10 degrees 54 minutes west, that is the compass needle points that amount to the west of true north. The declination is being reduced about seven minutes a year, so that in another 110 years, magnetic and true norths will coincide. A short table is given below to show how the declination has altered in London over the course of several centuries.

Year.	*Magnetic Declination*
1580	11° 15′ east
1665	1° 30′ west
1800	24° ,,
1819	24° 25′ ,, (probable maximum).
1925	13° 10′ ,,
1946	9° 37′ ,,

In some parts of the world the declination will obviously be east, depending on the relative positions of the North Pole, the magnetic Pole and the places in question.

Similarly with the magnetic dip-needle; this dips at angles that vary over the earth's surface. Immediately over the magnetic poles the needle dips vertically, on the magnetic-equator, which is neither coincident with the geographical equator nor a straight line, the needle lies horizontally, whilst at points in between the angle of dip will depend on the nearness to the magnetic Pole, in London the dip is about 66½°. Lines joining places

of equal dip are called isoclinic lines. The amount of dip changes also with time. All these phenomena, important in map-making and navigation, both marine and aerial, suggest that the earth acts as though a huge bar-magnet were thrust through it. Magnetic storms, that is periods when there are sudden and erratic movements of the compass and dip-needles, occur from time to time, and are associated with sun-spot activity (see Chapter XIII).

To sum up, the earth is a more or less spherical body rotating on its axis as it travels in an elliptical orbit around the sun, which is a star, but not the largest by any means among "the host of heaven". Possibly other stars possess planets as does the sun, that is many of the points of light to be seen in the night-sky may be central suns with solar systems similar to that to which we belong. It is known that two at least have a planet each. Our earth is an insignificant unit, from the point of view of size, in the universe, but it is our home, and as such is worthy of our consideration and study. The succeeding pages are intended to give some short account of what the earth is like, what has befallen it in the past, whence it came and what it has become.

NOTE TO CHAPTER I

WEIGHTS AND MEASURES

Some readers may be curious as to how the various dimensions of Mother Earth are measured, for we cannot run a tape measure around her or put her on a weighing machine.

To take dimensions first—it must be obvious that no accurate measurements could be made until man had first obtained a fairly good idea of her shape. Most early men conceived of the earth as flat, but there were some exceptions, e.g. Eratosthenes, a Greek geographer of Alexandria of the third century B.C. He was the first to attempt a measurement of the circumference. He compared the altitude of the sun at two points, one nearly south of the other, at the same day and hour. The two places that he chose were Alexandria and Syene, 500 miles due south of it. We now know that these places are not quite on the same meridian. The time and day were noon, June 21, i.e. the Summer solstice. Syene lies on the Tropic of Cancer and, therefore, at noon on the day chosen the sun was vertically overhead, at Alexandria it was $7\frac{1}{2}°$ out of the vertical. We should express that today by saying there is a difference of $7\frac{1}{2}°$ of latitude between the two places. Since $7\frac{1}{2}°$ of latitude represents a distance of 500 miles, then 360° (the complete circuit of the earth) will represent,

$$\frac{360}{7\frac{1}{2}} \times 500 = 24{,}000 \text{ miles.}$$

This was the figure arrived at by Eratosthenes and it is within 4% of the modern estimate, which is 24,860 on the meridian of Greenwich.

His estimate is all the more remarkable when it is remembered that he assumed that the earth was a perfect sphere and he knew nothing of the slight flattening of the globe in the polar regions or of the slight equatorial bulge.

Once the circumference of the earth is known it is obviously a simple matter to calculate such other dimensions as radius and surface area by simple mathematical means. Another consequence of great practical importance followed, viz. the ability to determine the distance between any two points on the earth's surface if the latitude or longitude of the two points be known. This is, of course, very valuable for marine navigation.

Measuring the mass of the earth is a more difficult problem and no attempt had been made or could be made—except for guesswork—until Newton formulated his laws of gravitation. He showed that the attractive force which one mass of matter exerts on another is directly proportional to the product of the masses and inversely proportional to the square of the distance between them, therefore the attraction between two masses M and m at distance r is proportional to $m \times M \div r^2$.

This was made the basis of a means for measuring the mass of the earth.

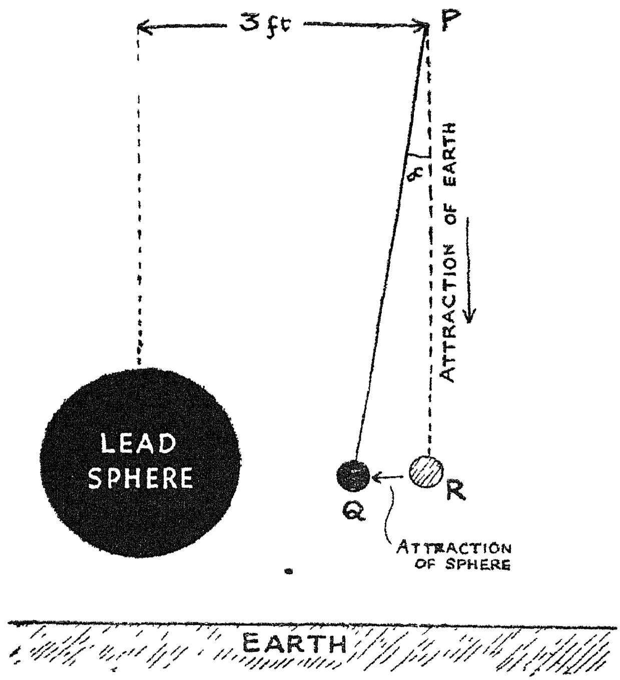

FIG 2 HOW THE EARTH IS WEIGHED

The actual instruments used are different in form although the principle—lateral displacement—is the same

NOTE.—Fig. 2 represents the principle, the actual apparatus is quite different. A small mass Q. is suspended from a point P. A large mass, e.g. a sphere of lead, one ton in weight, is placed at a known distance away. It is found that the pellet is pulled out of the vertical by a very small amount, which can be measured by means of a microscope. This deviation from the vertical is due to the pull of the mass of lead. It therefore follows that the ratio of the attractive forces of the lead and of the earth on Q is represented by $\frac{QR}{PR}$ which is tan α

If lead = mass m and earth = M
and r = distance of Q from centre of lead sphere
R = distance of Q from centre of earth
then

$$\tan \alpha = \frac{mR^2}{Mr^2}$$

Actual figures might be: lead sphere = 1 ton, r = 3 ft., angle α = 0·00000045°. Substituting in the above equation it will be found that M, i.e. mass of earth, equals $6{\cdot}5 \times 10^{21}$ tons.

THE COSMOS
consists of
GALAXIES or ISLAND UNIVERSES
[Four million can be seen photographically in Mount Wilson telescope. Each contains 100,000,000,000 stars.]
composed of
STARS
(of which our sun is one)
which may have planets forming a
SOLAR SYSTEM
made up of
PLANETS
(e.g. the Earth)
which may possess
SATELLITES
(e.g. the Moon.)

CHAPTER II

THE COMPOSITION AND STRUCTURE OF THE EARTH

THE internal structure of an individual can be determined by a surgical operation, or by dissection of the body, but in the case of Mother Earth, no operations that can be devised by human investigators can probe farther than a very little way into the outer layer, or skin. Below that there is a realm that is unknown, the nature and structure of which can only be studied indirectly. The many theories that have been put forward to explain the internal structure of our planet are a proof of the uncertainty of our knowledge on the subject. It is true, that the increasing study of seismic (earthquake) phenomena is helping us to understand a little more than was known before.

The Formation of the Earth

The phenomena of volcanoes gave rise to strange conceptions of what was to be found under the surface crust, in those days when science was not yet born and men drew quaint conclusions from the evidence of their senses. Some suggested that volcanic fires were the result of the combustion of deep-seated coal seams, whilst earlier still, and more fantastic, was the theory that the volcanoes were proofs of the existence down below of a fiery hell. Gradually it dawned on men's minds that there must be a sphere of rocky matter at a high temperature, below the cool outer layer of rocks, whilst some suggested that the inner portion of the earth was molten, e.g. Claviault, in 1743. Then in 1797, the great French scientist, Laplace, put forward the Nebular Hypothesis to account for the formation of the earth. This theory postulated a cooling body, hotter at the centre than at the surface, which would naturally cool first.

Laplace, as he studied the Solar System, noted several remarkable features about it, viz. the planets were all moving round the sun in the same direction, and further, the satellites (or moons) of the planets revolved around their parent bodies in the same direction, and the orbits of the planets and their satellites were practically in the same plane. This led him to conclude that the sun, planets and their satellites must at some time in the past have all been part of a huge mass rotating in the same direction. Since the mass must have occupied a great deal of space, the matter composing it must have been in a very tenuous state, i.e. it must have been gaseous.

Meanwhile, the great astronomer, Herschel, had discovered nebulae, or luminous patches in the skies and concluded that they were masses of

rotating gas. Laplace, therefore, suggested that the Solar System had originated from one of those very hot rotating gaseous masses. From physics and mathematics it was possible to show that as such a mass cooled it would shrink and separate into rings which would continue their rotation with the whole mass. As the rings cooled further they would break into fragments which would coalesce to form the planets. The larger central mass, the sun, would take longer to cool and it is still intensely hot.

This Nebular Hypothesis was generally accepted until comparatively recently, but what is called the "Accident theory" has now taken its place. This owes its origin to two American scientists, Chamberlain and Moulton, but is more usually associated with the name of Sir James Jeans who has popularized it in his writings.

It is suggested that in the case of our own sun—a star—there occurred, what is from its unlikelihood, an accident. Another star, journeying through space, is presumed to have approached so near to the sun that through its gravitational attraction, it tore a series of great masses of matter out of the sun—these becoming the planets. As the pirate star moved away it would tend to pull the masses after it until its distance became so great that the gravitational pull of the smaller sun on the masses counteracted the pull of the receding star, as a resultant of the two forces, the masses would take on a rotatory movement around the sun.

This "accident-theory" explains all the features of the Solar System noted by Laplace and it does what Laplace's Theory does not do, namely it accounts for another fact about the planets. As we go outwards from the sun, the planets gradually increase in size until Jupiter is reached, and then the dimensions fall off outwards (see p. 10). This is seen to follow on the new theory, for as the wandering star approached the sun it would at first only tear out small chunks—since its attraction would be small—and then as it came nearer larger masses would be torn away, and as it receded and its attraction diminished, so the pieces torn off would be smaller again.

During the last decade some criticism of the theory has been made, and astronomers are not yet satisfied that it represents the final truth. This has led some scientists to propound other theories for the origin of the Solar System and to one of these we now turn.

This, the Meteoric Theory of the origin of the earth and the planets, is due mainly to the work of Dr. O. J. Schmidt, a Russian, and only published about a year ago. It is still tentative but interesting.

The theory starts from two fundamental facts, these are the rotation of our Galaxy (already described) and the presence near its central plane of large masses of obscuring matter. Something must be said of that in order to understand the theory. Recent observational work has shown that there is a sort of fog, whose density differs in different parts of space, and which fills a great deal of the space between the stars of the Galaxy. This fog is densest in the Galactic plane where a beam of light is halved

in intensity after traversing about 3,000 light-years of distance. This cloud or fog is presumably composed of dust and small meteorites. Schmidt suggests that the sun during its motion round the centre of gravity of the Galaxy crossed through a cloud of dense fog and captured portions of it so compelled the particles to revolve around its centre.

These particles may revolve either with a direct or a retrograde motion, but if the sun passed through or near the edge of the cloud of particles then its density would not be uniform and in consequence more meteorites would revolve in one direction than in the other. Those revolving in the opposite direction to the main mass of particles would collide with the latter, lose their momentum and fall into the sun under gravitational attraction. Thus all the revolving particles would eventually revolve in the same direction. The small particles would gradually segregate into larger masses, the planets, and this process would go on as larger aggregates gradually drew neighbouring smaller ones to themselves, just as the earth "sweeps" up meteorites today.

The swarm of meteorites collected by the sun would have the form of a flat lens as a result of the centrifugal forces which would be developed as a consequence of rotation, so that the planets as they develop would have their orbits lying in approximately the same plane—the central plane of the lens—and as the meteorites from which they developed revolved in one direction so would the planets. At the moment the theory is new and novel, but there are many points in which it agrees with observational evidence, and its author is working on further implications of it.

The Interior of the Earth

Whatever origin is postulated for the Solar System, the infant earth, in common with the other planets, would have begun its separate existence as a very hot body—even on the Meteoric Theory the aggregates of meteorites would have been highly heated by the friction engendered by collisions and coalescence—which gradually cooled down as heat was radiated away from it. So the young earth having passed through an intensely hot, perhaps liquid, stage would slowly become condensed and consolidated, and a solid crust would form upon it. The surface would be rough and jagged at first for there would be up-wellings and eruptions of the underlying still-molten matter, the outer crust, thin at first, would be crumpled and contorted, owing to the contraction of the globe as cooling proceeded. A thick layer of clouds, full of steam and gases, would cover the surface of the sphere until cooling at the surface had proceeded far enough for the precipitation of the steam as rain, then denudation of the rough surface features could begin, seas would form in the hollows, rivers and streams run in the depressions, hills be rounded slowly, soil formed, sands and mud formed by erosion of the cooled matter, and as the stage was being

ready for the appearance of life; the great drama of organic evolution was about to begin.

Meanwhile, in the depths of the earth, the matter would still be intensely hot, the crust would only thicken gradually, since the heat took longer to escape through the solid crust than when it could radiate away into space.

By the middle of the nineteenth century it was considered that sufficient data was to hand for the formulation of a scientific theory of the earth's interior: all were ready to admit the fact that that interior was intensely hot, but there were different opinions as to the nature of the phase or state of the matter there.

Herbert Spencer, in 1858, suggested the centre must be gaseous, because of the high temperature (it may be mentioned that the temperature increases approximately 1°F. for every 60 feet descended), but this did not allow for the effect of compression on the boiling-points of substances. The terrifically high pressure that must exist at great depths would cause the boiling-points to rise so much that although potentially gaseous, or liquid, the probability was that the matter in the central region was solid, or viscous.

About the same time, Lord Kelvin, Hopkins, and George Darwin found that the rigidity of the earth was equal to that of a sphere of steel of twice the size, and they inferred that, therefore, the earth must be solid to the core. Other scientists, working from different standpoints, put forward other theories for the structure of the earth, but all agreed, more or less, in suggesting that there was an outer shell, composed of stony, cold material, the lithosphere, and an inner, hotter portion, the barysphere, composed of heavier, metallic matter.

Wilde, in 1890, suggested a solid crust, a gaseous core, and a liquid substratum separating the inner and outer parts; in 1897, Wiechert put forward the theory of a core, about 3,000 miles in radius, with a density of 7·8, mostly of iron, surrounded by a stony shell, with a density of of 3·0 to 3·4. In 1900, the Swedish chemist, Arrhenius, revived Wilde's idea, and suggested that the solid crust had a thickness of 25 miles, the liquid substratum of 150 miles, whilst all the rest was gaseous iron at a high temperature.

Then came a change in theorizing, in 1910, when the South African geologist, Dr. Schwarz, argued that volcanic phenomena indicated that the main mass of the earth below a superficial layer was cold and composed of unaltered ferro-magnesian silicates and iron.

A new method of study was opened up in England, in 1906, when Dr. A. Milne began to apply the records of earthquake shocks to a consideration of the internal structure of the earth. He found that the speed of earthquake waves varied according to the part of the earth through which they passed. In Fig. 3*a*, if an earthquake occurs at *O*, the waves emerging at *X* after passing through the outer portion will have travelled at a speed different from those which passed through the central

portion and emerged at *Y*. These speeds are not measured directly but are calculated from the times of arrival of the waves and the shock producing them.

By a comparison of many such measurements, Milne was able to suggest that there is a central core which transmits earthquake waves more slowly than the outer layers do, and that this inner core has a radius about two-fifths that of the whole earth. The variation in speed is a result of variation in density of the matter through which the waves

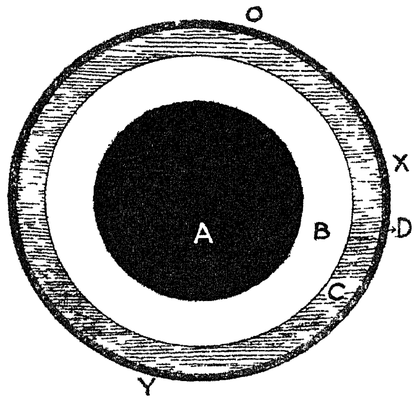

FIG. 3*a*. DIAGRAM TO ILLUSTRATE INTERIOR OF EARTH

A=central sphere, about 4,300 miles in diameter, incapable of transmitting distortional shock waves This means that it acts as a liquid The density (5 0 to 7·5) suggests that it is composed of nickel-iron in an unknown state B=Shell probably 1,000 miles thick, of density 4 75 to 5·0 Probably composed of a mixture of metals and silicates of an olivine type C=Basaltic shell, about 700 miles thick, with density 3·1 to 4·75 D=Granitic shell, discontinuous and with thickness varying up to 40 miles, thickest under the great mountain masses and thinnest under the oceans and may be absent under parts of the Pacific Ocean. Density 2·75 to 2·9.

travel. There is a further complication in the fact that the vibrations are refracted as they pass from one layer to another, just in the same way as rays of light are refracted or bent as they pass from one medium to another, for example from air to water.

The latest opinions on this subject (summarized in Fig. 3*a*) suggest that there is an inner sphere, some 4,300 miles in diameter, with a density that suggests it is composed of nickel-iron in an unknown state. The fact that this sphere is incapable of transmitting distortional shock waves indicates that the material composing it is acting as though it were liquid. It would seem, however, that the terrific pressure at such depths

below the surface would prevent liquefaction even at very high temperatures. It is this consideration that leads us to say the material exists "in an unknown state".

Density measurements of the earth also suggest a nickel-iron core. A shell some thousand miles in thickness surrounds the inner core, and this, judging by its density, is presumed to be composed of mixed metals and silicates of an olivine or basic type.

Outside this again there comes the basaltic shell, which has a density varying from 3·1 to 4·75, and a thickness of about 700 miles.

There is an outer discontinuous shell varying in thickness up to 40 miles. It is thickest under the great continental masses, especially the mountainous parts, and thinnest—in the ocean deeps probably absent—under the oceans. This outer shell is the lithosphere proper, and it is composed of igneous rocks, mainly of an acidic or granitic type, and sedimentary rocks. Igneous rocks are those which have consolidated by cooling and crystallization from a molten state. They may show all stages of crystallization from coarsely crystalline, for example, granite, to glassy, obsidian, for instance. They may be of all geologic ages. Those which contain much silica, usually in the form of quartz (rock-crystal, seen as the glassy crystals in granites), are classified as acid rocks, whereas those which contain no free silica (i.e. chemically uncombined with other elements) are termed basic.

The layered structure of the earth—like some gigantic onion—was obviously brought about during that period of its existence when the whole was molten, for there would then be possible a grading of materials according to their density under the influence of gravitational attraction, heavier materials would sink towards the centre and the lighter matter would remain as a sort of "scum" on the surface.

Much the same sort of thing happens in a blast-furnace, where the impurities, owing to their being lighter, rise to the surface, and the heavier iron sinks to the bottom. This grading process would considerably decrease in its effects as the earth cooled, especially after the first crust began to form, so that small amounts of some of the heavier minerals are found in the surface layers, as workable ores in some places or scattered finely through the rocks in others. It also accounts for the fact that mineral deposits, especially of the metals, are either found associated with igneous rocks, or in deposits that have been formed by the wearing away of such rocks, since igneous rocks on the surface today indicate extrusion of magma from deeper levels which would contain more of the heavier elements.

The Superficial Layers

Although little is known of the central core, barysphere, or centrosphere, much is known of the outer shell, the lithosphere, or skin of

Mother Earth. Parts of it are available to direct observation and study—for example, in cliffs, quarries, gorges, mines—and deeper parts of it can be studied indirectly by a consideration of volcanic, seismic, isostatic and radio-active phenomena.

The lithosphere is a stony envelope made up in the main of non-metallic compounds—a table of contents is given below. It is the lithosphere which forms the subject matter of geology. It is not, in its present form and constituents, an original part of the earth, for it has come into being as a result of weathering and other changes effected on the original cooled crust, of which no traces probably remain; its surface is the soil where grows or on which lives all that makes for human food and, therefore, existence, and from the lithosphere is won the mineral wealth that has made our civilization. All our raw materials come from it, for the only true primary producers are the farmers and the miners, those who till the soil and those who delve into the lithosphere.

TABLE SHOWING COMPOSITION OF THE LITHOSPHERE (AFTER F. W. CLARKE)

Element.	*Percentage in Crust. by weight*
Oxygen	47·02
Silicon	28·06
Aluminium	8·16
Iron	4·64
Calcium	3·50
Magnesium	2·62
Sodium	2·63
Potassium	2·32
Titanium	0·41
Hydrogen	0·17
Carbon	0·12

Small quantities of phosphorus, manganese, sulphur, barium, strontium, chromium, lithium, chlorine, fluorine, etc., are also found.

The commonest compounds are silica (oxide of silicon) in its many forms, quartz, chalcedony, flint—the main constituent of acid igneous rocks—of sandstones, grits and quartzites, and alumina (oxide of aluminium) which occurs in many igneous rocks in various combinations, and forms the main constituent of clays, shales and slates.

Rock Types

The rocks of the lithosphere are divided into three main groups:

(1). IGNEOUS—those rocks which have crystallized out from a molten state, that is, those which have been intruded into the surface rocks

from hotter regions below, or those which have been extruded on to the surface by volcanoes. The matter in the former group cools more slowly because of the capping of other rocks, and therefore will be more coarsely crystalline; examples are granite and gabbro, the acid and basic types. Extruded rocks, or lavas, will cool more rapidly because in direct contact with the atmosphere, and will be finely crystalline or even glassy; examples are basalt, a basic lava, and obsidian, a glassy lava. Pumice is an example of a lava that contained a great deal of gas which gave it its vesicular appearance.

(2). SEDIMENTARY—those rocks which have been formed by deposition, in the sea or in lakes, or on land by the wind, of material worn away from pre-existing land surfaces. They are thus usually found arranged in layers, or strata, and are said to be stratified. They are subdivided into several groups:

(*a*) *Calcareous rocks*—Limestones, including chalk, dolomite and oolites. Often fissured and cracked, therefore pervious to water; they usually form dry upland country like the Cotswolds, Chilterns, or Pennines. Chemically these rocks are mainly calcium carbonate.

(*b*) *Arenaceous rocks*—Consist of sands, sandstones, grits and quartzites. Usually these are porous and form well-drained and fertile soil, as in the corn lands of Herefordshire. They consist in the main of silica (silicon dioxide) grains cemented together.

(*c*) *Argillaceous rocks*—These are the mudstones, shales, clays and slates. They are impervious to water, and are, therefore, important in determining drainage, causing springs. They are composed mainly of alumina, an oxide of aluminium.

(*d*) *Carbonaceous rocks*—These are of organic origin and consist mainly of carbon, with other substances in small amounts. They include peats, lignites, coals, anthracites, and are of importance economically. Oil-shales and petroleum, bitumens and asphalt are all included under this heading, also.

(*e*) *Ferruginous rocks*.—Rocks with a high iron content, e.g. the clay-ironstones, haematites, magnetites.

(3). METAMORPHIC—rocks which have been formed by the alteration of other rocks, either igneores or sedimentary. This alteration may be produced physically, for example, when under great pressures clays are converted to slates; the change may be chemically produced as for example when the gases associated with the intrusion of igneous rock magmas produce chemical changes in the surrounding rocks, by combining with the substances already there and forming new minerals. Many semi-precious stones, such as topaz, beryl, ruby, are formed in this way. Metamorphic rocks are very varied since both the materials from which they have been formed and the methods of transformation can vary greatly

Fossils

Rocks of the above types can be of various ages, it does not follow that two rocks of the same type are of the same age. The dating of the rocks in relative order chronologically is done by study of the fossils that they contain, although there can obviously be no fossils in igneous rocks, and but rarely in metamorphic rocks, since any that were present in the unaltered rock would be destroyed by the changes that it has undergone. During the course of biological evolution there have been changes in the animals and plants that have lived upon the earth, simpler forms have slowly given place to more complex ones, whole new groups of living things have arisen, thrived and then become extinct, some forms have persisted almost unchanged through very long periods, others have been very numerous over a wide area for a relatively short time and then died out.

The net result is that each period in the past was characterized by a particular assemblage of living things, some of which occur in earlier periods, some of which are especially characteristic of it. Fossils are the relics or remains or even traces of such living creatures, and from a study of them it is possible to establish an order of succession in the rocks; but such an order is only a relative one, it gives us no information as to the actual age of the various rocks. Other methods to be described later are used for ascertaining such facts.

At certain periods in the past, certain groups of plants or animals were dominant in, or characteristic of, a wide area. In any rocks formed during that period, therefore, fossils of those groups will be common, and so will enable us to recognize and to date the beds. Such fossils are called zonal fossils, whilst a group of them is termed a zonal assemblage. A few examples may be given—the presence in a rock of fossils of ammonites (shells coiled in one plane, with varied ornamentation) indicates that the rock is of Jurassic age almost invariably (see pp. 45–6 for order of various rock systems), so would also the discovery in a rock of remains of the fish-lizard *Icthyosaurus*.

If a group had a comparatively short existence in time, it is especially useful in this connection, since its vertical range in fossil form in the rocks will be small and we are enabled to make smaller subdivisions; certain of the ammonites are very useful in this way, some species only occurring through a range of a few inches of rock. The zonal fossils may be regarded as sentences, the layers of rock as pages, and the whole series as a book, which has been bent and torn, and some of the pages crumpled and displaced from their original order.

It is the business of the geologist by reading the sentences to try and arrange them in some sort of order, so that the pages may be mentally rearranged in their proper order and the whole story of the book

read consecutively. This task has been going on now for over a century—it was first begun by an Englishman, William Smith, early in the nineteenth century—and we are beginning to gain some idea of the story of the rocks of the crust.

Fossils help us to reconstruct the past in other ways, too, for by a study of related forms to-day, their habitat and mode of life, we are able to infer something of the conditions existing at the time the animals lived whose remains we find fossil. For example, reef-building corals only exist today in warm seas where the water is clear and shallow; if we find fossil reef-building corals we infer that such conditions persisted at the time that they lived. Sometimes we can obtain confirmatory evidence from the nature of the rocks in which the fossils occur, in the case of the corals, for example, the containing rocks will be limestones, which are formed in clear water. A reconstruction of ancient climates and land and sea distribution can thus roughly be made.

There is one point worth mentioning here—namely the fact that most fossils are those of marine creatures, land-dwelling creatures or plants do not get the same chance of being preserved as do water-dwelling creatures whose remains can fall to the bottom and become fairly quickly encased in the deposits being laid down there. A further point to note is that only those living things which have hard parts, such as a shell, teeth, bones, etc., stand much chance of being fossilized, so it is that we know very little about the earliest forms of life that evolved on the earth, for they would have had no hard parts. In the earliest sedimentary rocks that contain fossils—the Cambrian rocks—we find representatives of many quite highly developed forms, but life must have existed for a long time beforehand for such creatures to have evolved.

Structure of the Crust

We now know that we can divide the lithosphere into two main divisions. This conception has been born of the new knowledge derived from recent studies of volcanic activity, gravity measurements and radioactivity. Examination of the lavas extruded from fissure-eruptions show that they are more basic in character than are the lavas from the more normal cone-volcanoes. Fissure-eruptions are those in which the lava reaches the surface, not from the central pipes characteristic of ordinary volcanoes, but along extended fissures or cracks in the outer crust. In such eruptions, the lava flows out in sheets, often covering considerable areas, not all in one eruption but in intermittent activity.

These eruptions are the result of activity which is deeper-seated in the crust than are ordinary volcanic eruptions, and they therefore afford some evidence respecting the nature of the lower layers of the lithosphere. The suggestion, therefore, is that there is a lower layer of basic, darker and more dense matter which underlies the upper, less dense and more acid

layer, from which the smaller and more localized volcanic eruptions are fed. This is, of course, what might be expected when it is remembered that a grading process would occur when the earth was entirely molten.

Confirmation of this idea of a two-layered lithosphere comes from the new knowledge of isostatic equilibrium. Dutton, an American geologist, in 1889 gave the name of isostasy to "that condition of equilibrium of figure to which gravity tends to reduce a planetary body, irrespective of whether it is homogeneous or not"; that is the heights of the mountain masses and the depths of the ocean floors are controlled by this equilibrium in accordance with the densities of the matter that forms them. Just as a block of balsa wood will rise farther out of a tank of water than will a block of oak, so a lighter mass of rock will rise farther out of the lithosphere than will a denser block. Confirmation of this idea came when plumb-line deflection measurements were made near mountain masses. For example, it had been calculated that the great mass of the Himalayas would deflect a plumb-bob by at least 15 seconds of arc out of the vertical in the Ganges Plain—on the assumption that mountains are just excrescences resting on the continental platform. Actual measurements showed, however, that there was a deflection of but five seconds. Similar discrepancies between calculated and measured results have been found in the case of the Andes.

Only one possible explanation will fit the facts—namely, that the density of the mountains and the crustal rocks under them must be relatively low. During the years 1909–12, Hayford and Bowie made many measurements of gravity in the United States, and they found that gravity differences die out at a definite depth, about 76 miles below sea-level. They called this depth the level of compensation. Above this level a block of the crust of any given surface area weighs the same as any other block of the same surface area, irrespective of the height of the surface of the blocks above sea-level. This implies that (and explains why) mountainous regions are composed of lighter materials than those in plains, or in areas beneath the sea. This difference in density of the materials may not be obvious on the immediate surface, the rocks of the mountains and of the adjoining plains may be similar, it is the deeper levels that are involved (see Fig. 3*b*).

These blocks of the crust tend to adjust themselves so as to maintain isostatic equilibrium. If there is an increase in weight either by deposition or sedimentation, over a given area, there will be a tendency for the block under that area to sink slightly. If material is removed, for example by denudation of a mountain mass, then there is a tendency for that mass to rise. In this way, mountains may retain their heights even though much material is worn off them. This idea also explains the persistence of what are called geosynclines. These are areas of long-continued deposition. As more sediment is added to the area so it subsides; this means further chance of deposition, since the area will continue to be covered with water.

Such a theory, well supported by many lines of converging evidence, supposes that there is, in the deeper part of the crust, a layer of material which although denser than the upper layer, yet acts as though it were a fluid (for there must be "flow" or adjustment in the layer to allow of the rise and fall of the blocks) in which the crustal blocks "float". The lithosphere is thus believed to be two-layered, the outer layer resting on and in the lower one.

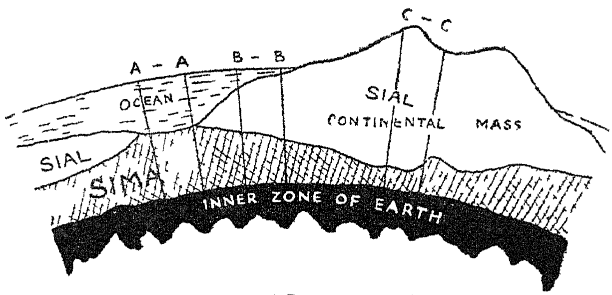

FIG 3b ISOSTASY

Generalized section through the outer levels of the earth's crust to illustrate the principle of isostasy Columns A—A, B—B, C—C, of equal surface area, contain, to the base of the sima, similar masses of sial and/or sima Surface protuberances, e g mountains, have corresponding sial protuberances into underlying sima

This theory has been taken a step further, as will be shown in more detail in a later chapter, by Wegener and others, who suggest that the crustal blocks of the continents may be likened to gigantic "rafts" of lighter material floating in an underlying and more basic substratum, and that these rafts are capable of horizontal movement as well as vertical movement. That means that they can change their places and relative positions, if they move horizontally, and if they move vertically, then the distribution of land and sea is altered; for example, subsidence of a continent would result in what is termed a marine-transgression—that is, an invasion by the sea of the lower parts of the continent, whilst uplift of a continent might result in the bringing of the continental shelf above water-level as a plain. More will be said about these movements later.

The central cores of the continents would seem to be more or less stable—not in position, but in persistence—they may rise or fall slightly in the basic substratum, but on the whole, deposition takes place round their edges, on the continental shelf, or on such coastal regions as get transgressed by the sea during a period of submergence of the continent, but whole continents do not become submerged.

The central cores of the continents are composed of very ancient rocks, and are termed "shields", they may contain portions of some of the

earliest crust formed on the surface of the earth. Usually these shields are low-lying and flattish, often covered with lakes. This is because they have been in existence as land-surfaces for so long that they have undergone considerable erosion.

Examples of such shields are the Canadian Shield—the heart of the North American continent, around which later sedimentary rocks have been deposited (see Fig. 16)—which forms an area of flat, lake-covered land lying around Hudson's Bay, and the Baltic Shield, which includes Finland and most of Scandinavia, and is also flattish, lake-covered, and is partly covered by the Baltic Sea. Other such shields are to be found in Peninsular India, the southern half of Arabia, the eastern part of Brazil, the western half of Australia, and, according to some authorities, the continent of Antarctica. Around the edges of these great blocks sediments have been laid down in many periods of the geological past, for the great geosynclines rim these blocks. These deposits have since been hardened into rocks, and subsequently folded and faulted by earth-movements as a result of the oscillations of the continents, with the consequence that fold-mountains often lie along the edges of these blocks, so adding to the land areas of the continents. Examples of such mountain chains are the Andes, lying down the western side of the Brazilian shield, and the Himalayas which run east–west along the northern edge of the Indian Shield.

CHAPTER III

THE TRANSMUTATIONS OF MOTHER EARTH

TODAY as we travel about the surface of the earth we find rocks of all sorts and types, igneous, metamorphic, sedimentary; we find districts where there is abundance of mineral wealth and countries that have little or none. Yet once the surface was made up of igneous rocks alone, rocks which had consolidated from the molten matter of which the younger earth was made. Probably nothing now remains of that first crust—at least, not visible on the surface. And yet from that first solid layer the rocks of today have been formed. Something has already been said about the changes wrought by weathering and erosion in producing new land forms and other features of Mother Earth, but little has been written yet about the way in which the various rocks and mineral have come into being.

As soon as rocks are elevated above the sea, they become subject to weathering by the atmosphere, by water in various forms, and by the differences in temperature of night and day, or of the seasons. And it is that weathering with its accompanying physical and chemical changes that has resulted in the production of the many types of rock that are to be seen today, and the process is still continuing.

Perhaps a word of explanation is needed here. Although to the layman the word *rock* implies something hard and solid, to the geologist a rock is an aggregation of minerals (and these are chemical compounds of definite composition). There may be only one sort of mineral in the rock, as in the case of a pure limestone, which consists almost entirely of the mineral calcite, or calcium carbonate; there may be many sorts of minerals, as in granite, which can easily be seen to consist of many different minerals, some clear and glassy (quartz), some pinkish and milky (felspar), some dark and shiny (mica)—all these can be seen with the naked eye; microscopic investigation may reveal smaller fragments of many others. The minerals in rocks may be compacted together so that the whole mass is hard and solid, as in a sandstone where the individual grains of quartz are welded together by a siliceous cement until sometimes the whole is hard enough to be used for making a grindstone. The mineral fragments may be small and loosely compacted, so that the whole mass is soft and yielding, as in the case of many clays, which consist mainly of small flakes or tiny fragments of alumina (an oxide of aluminium). To the geologist, granites and limestones, clays and gravels, are all rocks.

The Alteration of Rocks

Two kinds of changes can happen to an igneous rock (or any other sort for that matter) when subjected to weathering. There is the physical

change that occurs as the rock is disintegrated into its component grains or minerals, and there is the chemical change that may affect certain of the contained minerals. It is the combination of these changes that has produced the variety of rocks and mineral deposits of today, but those in their turn are undergoing change and will not persist as we now see them. The original solid crust was igneous, and a study of igneous rocks today teaches us that, in general, such rocks consist of the following minerals, so far as the main bulk is concerned—quartz, felspars, micas and ferro-magnesian minerals. A short description of these minerals is given for those unacquainted with them.

Quartz—an oxide of the element silicon, SiO_2 called silica. Sand grains are usually grains of silica. The clear crystalline variety is called rock-crystal and is used in jewellery, as are also the varieties known as amethyst, rose quartz, opal and bloodstone. Flint and chalcedony are also other forms of silica.

Felspars—these are chemical compounds consisting of silicates of potassium and aluminium (the pinky variety called orthoclase) or of sodium and aluminium (white variety, called plagioclase). The large pink or white crystals seen in granites are felspars.

Micas—familiar to most people as artificial frost flakes, and as "windows" in stoves. The commonest variety is white mica, or muscovite, which is a hydrated silicate of potassium and aluminium. A darker variety, biotite, is a hydrated silicate of iron magnesium, and aluminium. This is the dark shiny mineral seen in granite.

Ferromagnesian minerals—as the name implies these are chemical compounds containing iron and magnesia, often combined with other elements in the forms of their silicates. The commonest are hornblende, augita and elivine.

The proportions of these minerals varies in the different types of igneous rocks—for example, granites contain a high proportion of quartz, whereas there is little or no free quartz in the basic rocks such as gabbro and basalt. This of course will make a difference to the end products resulting after weathering of an igneous rock mass, but in general the following are some of the changes that take place:

It must be remembered that as rain falls through the atmosphere it absorbs or dissolves a certain amount of carbon dioxide, and this makes the water slightly acid: during thunderstorms there may be the production of nitric acid in the air through electrical action and this, too, will acidulate the rain water. Even after the rain has fallen it may become still more acid as it flows over the surface and dissolves organic acids from plant and animal remains. As this acid water percolates downwards into the cracks of igneous rocks, it starts chemical action on certain of the minerals. The felspars are the most easily attacked by the acid waters,

with a consequent breakdown into soluble salts of potassium and sodium, which are carried off in solution, and insoluble aluminium hydrate and oxide, which is carried off in suspension and later deposited as clay by the streams. It is this that accounts for the deposits of china-clay round the margins of the great granite masses of Cornwall and Devon.

The soluble salts may be later deposited owing to evaporation of the containing water, and so give rise to deposits such as the potash and other salt deposits of Strassfurt, Cheshire, and elsewhere. As the felspars are dissolved out of the rock, it undergoes a physical disintegration and the quartz crystals and fragments, which are insoluble, are carried away by streams, becoming rounded as they are borne along, and are finally deposited as sands, which may later become compacted into sandstone. The flakes of mica are also carried off, too, and it is very common to find glistening flakes of that mineral in sandstones, for example, on the cleavage faces of the Old Red Sandstone.

The ferro-magnesian minerals are even more important from an economic point of view, for their chemical breakdown results in the formation of magnesium and calcium carbonates, alumina and various compounds of iron. These are dissolved by the stream waters and borne away to be deposited elsewhere in a more concentrated form and so give rise to workable ore deposits. Other metals also occur in small quantities in igneous rocks, either pure, as in the case of gold, or in combination, as is the case with most metallic elements. Disintegration of the containing rock leads to a freeing of these metals which are later redeposited in veins, lodes and beds.

Deposits of gold formed by the transportation and deposition of the metal from the breakdown of igneous rocks are known as placer-deposits, and were formerly the main source of the metal. Sometimes the stream in whose gravels the gold was found could be traced back to the parent rock and that could be mined for the gold, but usually this is not an economic proposition as the metal is too scattered through the rock.

Today, however, owing to the invention of new machinery for dealing with large quantities of rock fairly cheaply, it is possible to crush and sieve the parent rock and abstract the gold. This is done in the Rand of South Africa, where rock, whose gold content is so scattered and fine-grained that the miners cannot see the gold with the naked eye, is yielding a great proportion of the world's supply of the metal. Nature, in the formation of the placer deposits, was doing the same thing much more cheaply even if far more slowly.

The local concentration of workable and valuable ores of industrial metals is due to many causes. As already stated, the minerals may be very sparsely distributed in the parent rock mass, but after the rock is disintegrated, a grading process takes place; some of the minerals are carried away in solution and may be deposited when the waters are subject to certain conditions—for example, great evaporation or bacterial action; some of the mineral particles are carried away in suspension and

are deposited according to their density as the stream loses speed, the heavier minerals will be deposited first forming placer deposits.

Again other mineral deposits are formed at the time that the great igneous masses are intruded into the pre-existing rocks. Highly mineralized water and gases at high temperatures and pressures often accompany the intrusions, and these are forced along any cracks and crevices in the surrounding rocks. There they may produce metamorphic changes, or may deposit their mineral content as veins or lodes.

It is for this reason that most mineral deposits, at any rate of the metals, occur in connection with igneous rocks. All the tin ores of the world occur in close connection with granite masses, for example, and they have been formed from such emanations from acid igneous magmas. On the other hand, chrome ores are always associated with basic igneous rocks. Relationships of this kind are, of course, of value in industry, and a knowledge of them can save a good deal of money and time in prospecting.

The calcium salts that are formed as a result of the chemical weathering of igneous rocks are usually in the form of the soluble carbonates and these are carried away in the stream waters, and eventually reach the seas. In some cases, the dissolved calcium carbonate may be chemically precipitated, when it forms a fine-grained limestone, or china-stone, after compactation; more often it will be precipitated by bacterial action, and result in a fine-grained limestone or an oolitic limestone. Much of the limey material that is carried down to the seas is, however, abstracted from the waters by living organisms, which use it for making their shells or skeletons.

All the corals, the molluscs, the gasteropods, and other groups today make their hard parts out of calcium carbonate. In the past, most of the marine animals did the same, and their fossilized remains now make up a great proportion of many limestones—for example, the coral limestones of Torquay (often polished for mantelpieces), the so-called "Purbeck Marble", which is a limestone almost entirely composed of fossil shells, whose sections seen in polished surfaces of the stone give it an appearance of veined marble, and the crinoid limestones from the Carboniferous.

The quartz and alumina are not chemically broken up, but are carried away to be deposited as layers of sand and clay, and in them will often be found the placer-deposits already referred to. It is obvious that the materials resulting from weathering will depend upon the nature of the igneous rock eroded.

The above description fits a typical acid rock. In the case of a basic rock where there is no free quartz, there will be no sand deposit resulting from its disintegration, whereas in the case of an ultra-basic rock, such as olivine, there will be no potassium or sodium salts, only iron and magnesium salts and clay. Again, the weathering depends on the meteorological conditions, if the igneous rocks outcrop in an arid district, then there will not be the surface waters to produce the chemical changes and weathering will be mainly of the mechanical type—that is, exfoliation, or

stripping off of surface layers through alternate expansion and contraction with temperature changes.

Of course, the first igneous rocks that were subjected to weathering on the earth's surface have long since been altered in many ways, and their derivatives have also undergone changes, too. In general, however, weathering of sedimentary rocks is mainly of a mechanical type, since the contained minerals have already undergone chemical change and have reached a form in which they are fairly stable so far as ordinary subaerial denudation is concerned. Limestones, sandstones and clays are constantly being weathered or eroded away, and redeposited elsewhere. There is, in fact, a continual change going on in the outer crust, and to the matter of the outer crust there is always new material being added as a result of earth-movements and volcanic activity, both of which processes result in the bringing up of matter from deeper levels.

Each time a sedimentary rock is eroded there is a further grading of its mineral constituents, and in that way there may be a concentration of valuable ores produced. For example, in the Jurassic rocks, of Westbury, Wiltshire, there are iron-bearing beds which were once used as a source of iron. These beds were probably laid down by a stream that flowed off a land mass that lay to the west, and which included what are now the Mendip Hills; these hills consist partly, at any rate, of Old Red Sandstone, which is rich in finely scattered iron oxides, and the Old Red in its turn was deposited in a gulf or lake into which flowed a stream that carried sandy material from St. George's Land (see Chapter V) which largely consisted of igneous rock. At each period of weathering there was a further concentration of iron.

Rock Changes at Deeper Levels

So far we have only considered the changes in the rocks that occur at or near the surface, but there are also changes taking place at lower levels in the crust. These later changes are not so easily observed, and much more needs to be learned about them before there can be any surety of what happens in the depths of the earth, but some speculations have been made and some of these are based on fairly good evidence. Sometimes, where there has been considerable buckling of the crust, rocks which formerly existed at great depths have been brought to the surface. There has also been some laboratory work done on minerals which enables us to theorize about the chemical changes produced in minerals under conditions of high temperatures and pressures.

As in the case of the surface rocks, the changes that ensue in the depths will be both chemical and physical. If material is in a state of fluidity, there will be some degree of grading according to the density of the minerals under the influence of gravity, heavier ones tending to sink lower than lighter ones. But generally, chemical changes will be the

more liable to occur. Ideas concerning these changes have altered considerably in recent years as physics and chemistry have advanced; the case of granite is a good example.

Since the time of the Scottish geologist Hutton (1727–96), granite has been regarded by most geologists as a crystalline plutonic rock—that is, an igneous rock which cooled slowly under other rocks, and so contained large crystals of various minerals Granite usually occurs in large masses in the core of mountains or folded areas, and where it is now exposed at the surface it is presumed that the sedimentary rocks that once covered the granite have been eroded away. Such occurrences of granite in Britain are the great granite masses of Dartmoor, Bodmin Moor and the Red Hills of Skye, to name but a few.

But there were some geologists who did not agree with the view that all granites were formed in this way—that is, by the slow cooling of an intruded mass of molten magma from below into overlying sediments; chief amongst such doubters were certain French workers and the English geologist Lyell. One of the objections raised against the usual view was the difficulty of explaining what had happened to the rocks that were displaced by the invading magma. It has always been noted, too, that the rocks surrounding granite masses show alteration to a greater or lesser extent, depending on the nearness or otherwise to the granite. This zone of metamorphosed rocks is called the metamorphic aureole.

As a result of intensive studies of many granite masses and their aureoles, some workers have now put forward the revolutionary theory that granite is not an igneous rock in the accepted sense—that is, the cooled product of a once-molten magma—but that it is rather an extreme example of metamorphism, or alteration of pre-existing rocks, either igneous or sedimentary, through the invasion and adsorption of the pre-existing rock by emanations of intensely hot liquids and gases.

The fact that granites are always associated with mountain-building receives an explanation on this theory, for it is suggested that the granitizing emanations come from abyssal magmas, either by gravitational differentiation or by being squeezed out of them by the growing "roots" of mountain ranges in the making. It has already been pointed out that when folding occurs on a large scale there is a downward buckling into the lower levels of the crust just as there is an upward buckling above the mean level and that the principle of isostasy implies a downward warping of the sial under the high mountain chains of the world. This downward warping may compress the deeper-seated magmas and so force mineralizing solutions and gases upwards into the core of the mountains, and so bring about a chemical alteration of the rocks sufficient to result in granite formation. On this view, granite becomes a replacement product and not an intrusive rock.

It must be admitted that not all geologists yet accept the view, either wholly or in part, and a good deal more data are needed before this major problem of petrogenesis is solved.

In these transformations that are ever taking place within the crust, sedimentary rocks also become involved, often with results that are of benefit to man. Limestones, in particular, when carried to deeper levels of the crust by earth movement, are susceptible to physical and chemical changes. If the limestone is pure—that is, contains little else besides calcium carbonate—then under the influence of the high temperature and pressure at deep levels in the crust, the calcium carbonate will become changed into the crystalline form, called calcite, and crystals of roughly the same size will be formed and the whole welded together into a hard saccharoidal rock, the true marble, such as the statuary marbles from Carrara, in Italy.

This is one of the changes that has been experimentally verified for, over a century ago, Hall, the Scottish chemist, subjected powdered chalk to heat and high pressure and produced a marble-like substance. This change of limestone to marble may also be brought about at levels nearer the surface, if limestone is invaded by molten magma as, for instance, in the case of the Chalk of Antrim, where after the flow of basalt sheets during the Eocene, the surface of the underlying Chalk rock was converted into marble But the process is not so complete as in the lower level change.

Limestone may also act as a chemical reagent in producing mineral deposits of economic value. There are workable deposits of magnetite—the black oxide of iron—in Sweden and in the United States, which appear to have been formed as a result of iron-bearing magmatic liquids invading limestone. A chemical change took place whereby the iron was deposited as magnetite and the replaced calcium carbonate was carried away in solution.

The presence of impurities, especially of certain elements, in a limestone that is subjected to heat transformation may result in the formation of semi-precious stones such as garnets and olivine. In fact, many of the precious stones are due to chemical changes that have taken place during metamorphism, and they are usually to be found in the aureoles surrounding igneous rock masses. In addition to the examples already cited, there are topaz, often found in metamorphic aureoles, spinel, found in altered limestones; and serpentine, which is an alteration product of olivine.

Cycles of Chemical Change

There is thus a perpetual metamorphosis taking place in the crust, the elements are continually being reshuffled, forming now one compound, now another, depending on the condition to which they are exposed.

This reshuffling is aided by the processes called collectively denudation, and by the upwellings of new material in the form of magmas from the depths of the earth. In the changes that take place, life plays a part, thus

showing the interdependence of the organic and the inorganic on the earth. Many of the changes brought about by weathering involve oxidation—that is, the combining of certain elements with the free oxygen of the atmosphere—and the consequent formation of new compounds, for example, iron is usually found in oxide form in weathered rocks.

But there is no free oxygen in the crustal rocks, and there was none in the primeval atmosphere. Where, then, has the oxygen that forms one-fifth of the atmosphere come from? So far as we know, the only mode of formation of free oxygen is organic action, mainly the action of green plants which in sunlight absorb carbon dioxide and liberate oxygen. The carbon is retained by the plants for the formation of their tissue, and that is why plant remains may under suitable conditions form deposits of peat or coal; and that also explains why no carbonaceous deposits in the form of coal are older than the Devonian, because such could not be formed until a luxuriant land flora had evolved.

The other source of free oxygen is the action of certain bacteria on nitrates and sulphates, which are reduced to ammonia and sulphides respectively. Some bacteria have the power of attacking water containing sulphides and precipitating sulphur. Some sulphur deposits may have been formed in this way. The presence of abundant iron pyrites—the sulphide of iron—in the Rhaetic rocks at the base of the Jurassic series may be due to the decomposition of the numerous fish of the time. Many limestones have been formed by biological action as already indicated.

The so-called "nitrogen-cycle" is another example of the way in which biological action is helping in the constant interchange of elements between the atmosphere and lithosphere. Certain plants, mainly the leguminous ones—peas, beans, clovers—have on their roots nodules which contain a type of bacteria which is capable of absorbing the nitrogen from the air and converting it into compounds that are assimilated by the plant. When the plant decays, some of that nitrogen is liberated back into the atmosphere in various forms, and some is carried off in solution in the moisture of the soil, and so becomes part of the crust of the earth. Nitrogen, although an inert gas, is in compound form an essential element in plant and animal life, and this cycle which links earth and sky is a means by which it is made available for living things.

The Geological Time Scale, or Series

Geologists divide past time into eras and periods whose names are also given to the rocks formed during them. If we retain the analogy used elsewhere whereby the strata are regarded as leaves in a book, then the eras are the parts, and the periods are the chapters, of the book of the earth's crust. The names of the eras refer to the type of life then existing, whilst the names of the periods usually refer to the place where rocks of

the age concerned were first studied, or to some special characteristic of them. Since the branch of geological science which deals with the classification of strata—stratigraphy—was first developed in Great Britain, many of the names refer to British areas. This is rather unfortunate since many deposits are better developed in other places. Whilst many countries still retain the British nomenclature in the main, they also use alternative names in some cases. As will be seen from table on p. 87, the lengths of the periods and of the eras differ considerably.

For ease of reference, and especially when reading Chapter V, a full classification is given below, together with some explanatory notes. It should be noted, however, that several variant divisions of the pre-Cambrian are in use, here only the simplest is given.

(1). PRE-CAMBRIAN ERA. This is longer than all the succeeding eras put together. Rocks of this era are the oldest of those appearing at the surface.

(*a*) *Azoic* (without life).—No trace of fossils.

(*b*) *Eozoic* ("dawn of life").—First appearance of life in form of a few doubtful fossils. Living forms would have been soft-bodied.

Rocks of pre-Cambrian age occur in the Highlands of Scotland, Anglesey, Malvern, Charnwood Forest, Shropshire, Lizard Peninsula, etc.

(2). PALEOZOIC ERA ("old life")—Sometimes called Primary Era. Rocks of this era contain fossils of extinct forms of life.

(*a*) *Cambrian Period.*—First studied in Wales (Cambria). Earliest group of rocks with good fossils. Occur in parts of Scotland, North Wales, and at a few other places in Welsh Border area.

(*b*) *Ordovician Period.*—Rocks of this period well seen in North Wales, and named after old British tribe that inhabited the area, the Ordovices. Also occur in Lake District.

(*c*) *Silurian Period.*—Named after ancient British tribe that inhabited South Wales, where these rocks were early studied. Occur along Welsh borders.

(*d*) *Devonian or Old Red Sandstone Period.*—Called Devonian because the marine sediments of this age are found in South Devon, elsewhere the deposits are non-marine, lacustrine or terrestrial deposits, usually red sandstones, as in Herefordshire, Monmouthshire and Scotland.

(*e*) *Carboniferous Period.*—So named because amongst the rocks of this age are the coal measures. Exposed in the coal-fields of Britain, in the Mendips, Pennines and South Wales.

(*f*) *Permian Period.*—Named after the Russian province of Perm, where the rocks of the age are well developed. In England there are few if any marine deposits, but desert sands, seen in Midlands

(3). MESOZOIC ERA ("middle life").—Sometimes called the Secondary Era.

(a) *Triassic Period.*—So called because of the three-fold division of the rocks of this age in Germany where they are well developed. In Britain there are no marine beds, only lake and desert deposits, usually red sands and marls. In the past, the Permian and Trias rocks of Britain were often termed the New Red Sandstone. Occur in Midlands.

(b) *Jurassic Period.*—Named after the Jura Mountains where rocks of this age are well developed. In Britain, Jurassic rocks form a belt running across England from the Dorset coast to the east Yorkshire coast, including the Cotswold Hills and the Lincolnshire and Yorkshire Wolds.

(c) *Cretaceous Period.*—The principal rock of this period is the Chalk, hence the name. Developed in the Chilterns, North and South Downs, the Weald and Salisbury Plain.

(4). CAINOZOIC ERA ("new life") or Tertiary Era.—Contains still existent forms of life.

(a) *Eocene Period.* ("dawn of the recent").—Rocks of this period contain fossils of still living species, and occur in the London and Hampshire Basins.

(b) *Oligocene Period* ("few recent").—Rocks contain some still living forms, and occur in the Hampshire and Isle of Wight areas.

(c) *Miocene Period.*—Rocks contain a minority of living forms as fossils, hardly seen in Britain which was a land area during the period.

(d) *Pliocene Period* ("majority of recent").—Rocks of this age occur in East Anglia.

(5) QUATERNARY ERA ("fourth in order") or Post-Tertiary.

(a) *Pleistocene Period*, or Glacial Period.—Time of great Ice Age. Glacial drift of this age covers much of northern and eastern England.

(b) *Recent Period*, or post-Glacial.

CHAPTER IV

EARTH'S CHANGING FACE: (1) TODAY

POETS have written of the "eternal hills", we talk of things being as "firm as a rock", and most people regard the face of the earth as more or less static. Unless men live in those regions where volcanoes are active or earthquakes occur, they regard the earth itself as a quiescent stable body. On the whole, experience would suggest that men are right in regarding the scenic features as fixed and changeless, but that is because the changes that are continuously taking place on the earth's surface are so slow and, in general, take so long to effect easily visible results, that in the space of an individual's life there is little marked alteration to be observed.

But this is an illusion. Every stream that flows down to the seas of the world bears in its waters matter, either in solution or suspended, in the form of sand, silt or mud. The sand-banks and mud-flats at river mouths bear witness to this fact, as does the colour of the waters and the fact that the seas are salt. As the moving stream-waters meet the sea and their motion is retarded, their carrying power is lessened, and the suspended material is deposited. The heavier and larger particles are deposited first, i.e. close inshore, whilst the smaller particles are carried farther out. There is thus a grading of the deposits, from pebbles and coarse sand to fine mud and silt off-shore. This can be observed at the mouths of many rivers. When streams flow over rocks containing the coloured ores of iron, the water dissolves some of the material and then becomes coloured.

In fact, there is a continual cycle of changes always going on on the surface and under the surface of the earth. Denudation, i.e. the wearing away of the exposed surfaces, and especially the higher ones, by various agents to be described in more detail below, tends to reduce the surface to a more or less even plain, by removing the protuberances and filling up the hollows with the material worn off the high ground. But there are compensatory processes too, for new deposits are continually being formed, and these in their turn become hardened and compacted into rocks which, sooner or later, are elevated by forces at work within the crust to form new high ground. The whole cycle then begins all over again.

It is part of the business of the science of Geology to try and reconstruct the changes by studying the rocks of the crust and interpreting the evidence which they afford of those changes. Since the changes form a cycle, it does not matter at what point we start our description of it, but for convenience it is usual to start with the denuding processes, because they can be the more easily observed, and some at least of them

are familiar to most people who live in the country. Fig. 4 illustrates the cycle of changes in summary form.

Denudation

The foot of almost every cliff, or steep slope that is not covered by vegetation, has a scree, i.e. a heap of stones formed by the wearing away of the cliff above. Alternation of heat and cold, frost and rain, wind and

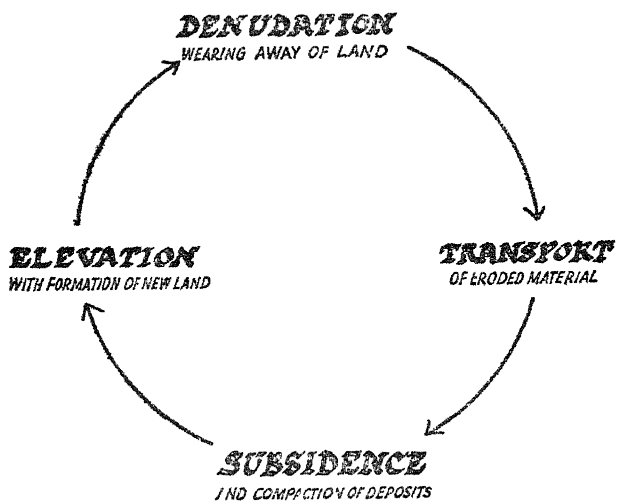

FIG. 4.
CYCLE OF CHANGES through which the surface of the earth passes

sun, all help in this wearing-away process, or denudation. If there were no compensatory processes, all the land areas of the world would in time be worn down to a plain-like surface; the rivers would grade their valleys —that is, they would wear them down to a smooth profile from source to mouth—and they would widen them as they meandered over the gently sloping surface that would result.

The above is one of the ways in which the face of Mother Earth is being continually changed—her wrinkles are being smoothed out. If these were the only changes that took place, Earth's face would get smoother with age. Then there is the erosive action of the tides and waves on the shores of the continents and islands. Parts of England, for example, are being worn away at an alarming rate, especially on the coasts of East Anglia and Yorkshire, where legends, and facts too, attest to this erosion. A Royal Commission which investigated the matter, reported in 1911 that during the preceding 35 years the British Isles had lost in

this way just over 10 square miles. Much protective work is now being done along our coasts to prevent further loss, such as the building of groynes and sea-walls. It must be remembered, too, that there is a counterbalancing process, viz. the formation of new land, in the form of mud-flats and sand-hills, especially along parts of the western coasts.

Where cliffs or hill-slopes are very steep, and if the geological formation favours it, then slipping will occur. Sedimentary rocks are arranged in layers or beds, lying one on the other, sometimes horizontally, but more often tilted, they are then said to dip. If a thick sandstone or limestone bed lies on a clay, and the whole sequence dips steeply towards the exposed cliff-face, then the conditions are set for a landslide. Rain-water percolates down through the upper bed, but cannot pass through the impervious clay, and so runs along its upper surface, thus lubricating

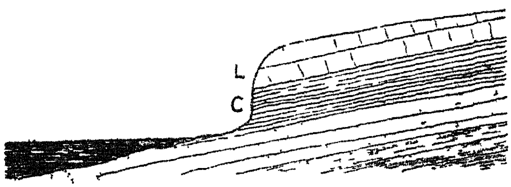

FIG. 5. LANDSLIDES

Conditions favourable to a landslide. Massive limestone beds (L) rest on clays (C) and the whole series of rocks dip towards the sea which undercuts the cliff, and this, together with the tendency for the limestone to move down the dip slope on clay, sets up the necessary conditions for a slip.

the junction and weakening the bed above. Often, too, in the cliff-face the lower part of clay is already undercut, and this adds to the insecurity of the rock above. Slips result sooner or later under such conditions. The famous undercliff of the Isle of Wight illustrates the process, there the Chalk and Greensand rest on Gault Clay, and great slips have taken place along the south side of the island, resulting in the change of level of a large area of land. In September 1928 a tract of some 60 acres moved a considerable distance near the well-known Blackgang Chine. Similar slips have occurred in the past, and still do, near Lyme Regis, in Dorsetshire.

Geologists tell us, and anthropology supports them, that not so long ago—some 10,000 years or so—there was a land connection between France and South-Eastern England across what is today the Straits of Dover. The waters of the English Channel at length broke through that ridge and made Britain an island. Ireland, too, was not so long since joined to England, but there, too, sea erosion has effected change. The Isle of Wight must once have been part of the mainland. The smaller

islets of Lundy, Steep Holm and Flat Holm, in the Bristol Channel, and many another around our coasts were once joined to the parent island.

The western coast of Europe was formerly much farther west than it is today. The tracts now occupied by the North Sea, Irish Sea and English Channel were then low-lying land from which the present British Isles stood out as higher ground. Across that "North Sea Plain" there then flowed a continuation of the present Rhine to join the North Atlantic away to the north-east of Scotland. The Thames was a tributary of that greater Rhine. The Severn then flowed over low-lying land between the hilly regions that are now Cornwall and Ireland to fall into the ocean away to the south-west of the latter country. The changes that brought about the present distribution of land and sea were partly due to movements of the crust of the earth and partly due to the action of denudation described above.

The distribution of animals and plants, no less than the geological structure of the islands and continents, show us that there must have been considerable changes in the distribution of land and sea all over the world in the past. If, as is believed on good evidence, man originated somewhere in central Asia, how did he get to Australia? Most probably, in the first instance, by land. The many islands which run in an arc-like arrangement from Malaya to Australia represent the tops of a mountainous ridge of land that once connected the two regions and which has now foundered beneath the Pacific Ocean.

In this and other cases, e.g. the West Indian Islands, earth-movements have played a large part in producing the islands, although erosion has played its part too. This cutting off of Australia resulted in the development of the peculiar plants and animals of that continent, for once the land bridge with Asia was broken there could be no influx of new species and those already in Australia would be conditioned by their environment. Animals, and other living creatures, when isolated in this way tend to develop along specialized lines due to the effect of their environment and the absence of other types with which they might mix.

Glaciers play a part, too, in wearing away or eroding the rocks over which they flow, for like some gigantic block of sandpaper, the glacier abrades the valley in which it flows. There is this difference between glacial erosion and river erosion, to the glacier all rocks are alike, it cuts them all down more or less evenly; the river differentiates, and wears away softer rocks more quickly, so that harder beds stand out and give rise to waterfalls or rapids. As the glacier melts at its lower end much of the heavier and larger masses of rock carried by it are dropped right away and form a heap, or moraine, whilst the waters that result from the melting are very muddy, for they bear away the finer detritus in suspension.

The numerous water-filled hollows that are to be found in areas that once supported glaciers but from which these have now gone, also attest to the erosive power of these ice-rivers. It is probable that this scooping

action of glaciers played no small part in forming the huge hollows in which now lie the Great Lakes of America.

During the Pleistocene Period, which is the time-period immediately preceding the present—some half million years ago—there was a great southwards extension of the ice sheet that covers the polar area, and as a result great glaciers and ice-sheets covered great tracts of Eurasia, North America and Britain. In the latter country the ice extended south as far as a line drawn from the mouth of the Thames to that of the Severn. Many of the valleys of the Pennines, Wales and the Lake District were then deepened and widened by the glaciers which radiated out from the higher ground of those districts. Such ice-carved valleys are usually fairly easy to detect, for glacial valleys have a cross-section shaped like a letter U, i.e. the bottoms are rounded, whereas rivers cut valleys that have a cross-section like a letter V.

Underground streams, such as are often found in those areas where the surface rocks are thick limestones, also help in altering the face of the earth. Rain, as it falls, dissolves a certain amount of carbon dioxide from the air (and even nitric acid during intense thunderstorms), and this results in the formation of the weak acid, carbonic acid, which can dissolve limestone.

Limestone is a pervious rock, i.e. it has numerous cracks and joints, so that the acidified waters easily percolate downwards and dissolve out hollows in the rock. If an underground stream is formed, as it may be if clay underlies the limestone, and the waters cannot travel downwards and must travel along the line of junction, then a series of large channels and caves may result. If these caves lie not far below the ground surface, their tops may become weak and fall in, with the consequent formation of a gorge. Some consider that Cheddar Gorge in the Mendips was formed in that way.

Although it may seem strange to those who live in England where, in general, the winds are light to moderate in force, and the earths' surface is usually well covered with vegetation, the wind can be a considerable agent both of denudation and of transportation. Yet, even in England, there is among several similar examples, the famous church of St. Piran-in-the-Sands, near Perranporth, in Cornwall, which has been buried by sand-dunes piled up by the prevailing south-westerly winds, and which is now uncovered. It is in areas where the surface vegetation is scanty or absent that the effects of wind erosion are best seen. No one who has experienced a desert sandstorm, or seen the pitted features of the Sphinx, can doubt the capability of the wind both to carry sand grains and to use them as erosive agents.

In some parts of the world this erosive action due to winds is very serious. Every wind that blows across the southern half of Australia removes soil, and hundreds of thousands of tons are removed each year in this manner. From the Mallee district of north-western Victoria there extends northwards into the interior a large area whose surface is covered

with a fine red dust. It is as fine as flour, and when lifted into the air by winds will only settle again in a dead calm, unless it is brought down by rain.

It is this reddened rain which often causes damage in Melbourne and other parts of Victoria after a spell of hot weather. The hot winds that in summer blow over central Australia carry great quantities of dust up to heights of five miles and over. During the autumn, when the South-East Trades blow, great quantities of this dust are blown as far as the Dutch East Indies. If the wind blows from the west, then the dust clouds are carried far out over the Tasman Sea, where recent samples taken from the sea-floor show the presence of a deposit of red sludge. The dust clouds often travel very great distances. One severe storm in 1929 was studied and its effects noted, and it was calculated that it carried away some 50,000 tons of Australian soil to deposit it on the islands of New Zealand alone. The much greater amount that was deposited in the intervening sea cannot be estimated.

Denudation by water

Although it is true that such agencies as glaciers, wind currents and tides do affect the earth's surface and destroy the surface features to some extent, there can be little doubt that in the temperate regions such as the British Isles, the main agent of denudation, as weathering and erosion are collectively called, is running water. Of the rain that falls, some seeps into the ground, some is evaporated and some runs off—an average proportion is about one-third in each way. The surface water, under the influence of gravity, runs downwards, small rivulets coalesce, forming streams and they, in turn, combine to form rivers which eventually find their way to the seas.

Running water erodes away the land in two ways—it cuts downwards into the bed in which it is running, and it cuts into the banks, so that rivers and streams both gradually deepen and widen their valleys. The amount of downward and lateral cutting is determined to some extent by the nature of the rocks over which the streams flow and by the rainfall of the region through which they flow. Naturally, a stream cannot wear away a hard rock like granite as fast as it can cut down into a soft rock such as clay. Again the erosive action varies with the amount of matter carried along by the stream or suspended in it. Clear water will not erode as fast as silt-laden water moving at the same speed would do.

Up in the mountains and hills, where the slopes are steeper, the streams are faster, and therefore cut down quicker and do less lateral erosion; farther down their courses, where the slopes are gentler, streams tend to meander and do more lateral cutting instead of vertical cutting

Eventually, of course, if there were no earth movement, and a stream persists long enough, it works down to a profile below which it cuts down no farther; any further erosive action it performed is lateral only. Such a stream is said to be mature.

A characteristic of the valley of such a stream is that there are no interlocking spurs projecting out into the broad valley, they would long since have been eroded away. A young and immature stream, on the other hand, usually has a valley that winds between spurs of higher ground projecting from the sides of the valley. Of course, if a river basin is elevated then the downward cutting begins again, and the river is said to be rejuvenated.

The shape of a main valley is also conditioned by the number of tributaries that it receives—these tend to widen the main valley. On the other hand, if a stream starts in a region where there is a fairly high rainfall and then flows through an arid region, there will be few tributaries in the latter region and little or no erosive action of the banks due to surface water. Such a state of affairs exists in Colorado and has given rise to the famous Colorado Canyon. The river of the same name receives no surface water from its banks, and therefore the banks become almost vertical, there is no lateral erosion, only downward cutting. The wide valley of the Thames, on the other hand, is partly due to the amount of rain that falls on the hills that border its entire length on the north and south. Much of this rain runs off as surface streams, and these cut back the boundaries of the Thames valley as they flow down the slopes to join the parent river.

Since the rocks of the crust differ in their nature from place to place, it usually happens that a river flows over many different types of rock in its course, and these differences will be seen in the shape of the valley. The valley will be narrower where it passes through harder rocks and wider in softer rocks. The Bristol Avon affords a good example of this. Above Bristol, this stream flows through a relatively wide valley, the rocks being mainly Liassic clays; but at Bristol the river turns to cut through the hard Carboniferous Limestone ridge of the Downs, with the result that it becomes the narrow Avon Gorge.

If the harder rock is only a thin band lying horizontally, or dipping slightly, then a waterfall or rapids may be produced. This is exemplified in the case of Niagara Falls where the Niagara River flows over the hard Niagara Limestone. Although the hard rock retards the downward cutting of a river, it does not stop it, and erosion goes on slowly, so that rapids and waterfalls are gradually reduced or cut back. The latter is happening in the case of Niagara, where the falls are receding towards Lake Erie, and eventually, unless otherwise prevented, the river will work back until the falls disappear. The falls have actually been cut back seven miles since the river began to run again after the disappearance of the ice-sheet that covered the area in Pleistocene times. This ice probably disappeared about 20,000 years ago.

Deposition

There are, on the other hand, constructive or building-up forces at work. Reference has already been made to the silt and sand deposited at river mouths. This is one way in which considerable tracts of new land can be created. In the northern end of the Adriatic Sea a tract of new land some 100 miles long and two to 20 miles in width has been formed in the past 2,000 years. The accumulation of sediments at river mouths was noted even in early times and Herodotus (484–424 B.C.) realized that the delta of the Nile was being enlarged by the mud being brought down by that river, and he calculated that if the Nile had flowed into the Red Sea instead of into the Mediterranean it would silt up the Red Sea in 10,000 years. Especially is this building up of river deposits noticeable in the case of those rivers that flow into comparatively land-locked and hence current-less seas, e.g. the Mississippi and the Ganges, in addition to those already cited. Where there are strong currents along the coast opposite the river mouth then the deposits are carried farther away and deltas do not form.

The name alluvium is usually given to the fine-grained material deposited by rivers, either at their mouths or on their flood-plains, i.e. the low-lying ground in their lower reaches The shells and other hard parts of marine animals also help to add to this accumulation on the sea-floors, and in areas where there is no big river bringing rock waste to the sea, these organic remains may form the greater part of marine deposits. Great thicknesses of deposits, subsequently hardened and compacted into rock, have been formed in this way, e.g. the Chalk which forms much of southern England, consists in the main of the remains of small marine creatures, the Foraminifera, which lived in the clear waters of the seas of the Cretaceous Period. (See next chapter.)

It is not only in seas that rivers deposit material. Moving water can carry matter, whereas stationary water will not do so. The amount of material carried and the size of the particles carried or rolled along varies with the velocity, e.g. if the velocity of a stream is doubled it can roll along pebbles and boulders six times as large as it could before, so that when moving water meets a body of stationary water the material carried will be deposited.

Lakes form such stationary bodies of water, and they have been termed "transitory features of the landscape", because every stream that flows into them brings sediment which slowly, but surely, fills up the lake, for there are no strong currents as there are in the seas to carry the sediments away, and in any case the lake is a limited body so that it can only hold a certain amount of material. Small deltas can often be seen reaching out into the lake and these grow and often coalesce, and eventually the lake is converted into a level marshy tract.

This process can often be observed in quite small ponds. A good illustration of the deposition of water-borne matter by the checking of the currents can be seen in almost any gutter during a rain-storm. If there is any impediment, such as a stick, twigs, straws, etc., the water will drop any mud, leaves or other debris that it may be carrying and a small deposit will quickly be formed.

Earth-Movements.

The greatest of all the forces, however, that produce effects contrary to those of denudation, is that of earth-movement. The slow contraction of the interior of the earth—still intensely hot—due to gradual cooling, results in the production of stresses and strains in the already cooled and rigid crust, which has to accommodate itself to a shrinking interior. The force of gravity tends to pull the crustal layers into the centre of the earth with the result that buckling of the strata composing the crust occurs. This buckling may cause sediments that have been laid down on the sea floor to be brought above sea-level, it may fold the rocks so that hills and mountains are produced, e.g. the Alps and the Himalayas were formed in this way.

The great mountain system that stretches across Europe and Asia from the Pyrenees, through the Alps, the Balkans, the Caucasus, the Himalayas and on into Malaya, sending out various branches such as the Apennines, the Carpathians, the Dinaric Alps, the ranges of western China and of Burma, is all composed of rocks that have been intensely folded and contorted.

This folding began in the early Tertiary Period, some 50 million years ago, and is still proceeding to some extent. In still earlier geological times, similar folding of the crustal rocks formed the Pennine and Mendip Hills of England. The western coasts of the American continent are formed of fold mountains of the same age as those of Eurasia, viz. the Rockies, Coast Ranges and Andes. In this case, the pressure was east-west so that the ranges run north–south. The formation of such fold-mountains can be easily illustrated, on a minute scale, by laying a number of pieces of cloth, or paper, on a table and pushing inwards from two opposite sides of the pile.*

An interesting feature of this folding of the crust, so far as Europe at least is concerned, is that the axes of the east–west folds lie successively farther south as we get nearer to our own times The last-formed series is the Alpine-Himalayan chain mentioned above, formed in the Tertiary Period (see last paragraph of Chapter III). The next oldest series of great

* Although mountain-building has here been explained along conventional lines, that is, as being due to the contraction of the earth, it will be seen later that some geologists invoke the action of other forces in mountain-building The effect of earth-movements in rejuvenating the face of the earth is, however, in no way altered even if we change our views as to cause.

folds also runs almost east–west, through the Mendips, Brittany, the north French and Belgian coalfields and into Germany. This folding, which took place at the end of the Carboniferous Period, formed mountains which have since been much denuded, but of which the former presence can be deduced from the rock formation.

Earlier still, a series of earth-movements that reached their climax in

FIG 6 GEOLOGICAL STRUCTURE OF EUROPE

The ancient "continental shield" of Fenno-Scandia is shown shaded. The thick black lines indicate the fold-mountains of Tertiary age. Note that the "shield" is low-lying and lake-covered and partly inundated by the Baltic Sea. Compare the Canadian Shield, Fig. 16

the Devonian Period, produced fold-mountains stretching across what is now southern Scotland and north-eastern Ireland, whilst far back in the pre-Cambrian Era, more than 500 million years ago, another great fold-mountain system was formed in the region now occupied by Sutherland, Ross and Lewis, in Scotland.

Sometimes, the folding has been so intense that a structure known as an overthrust results (see Fig. 8, which illustrates this better than any description). In this case, older rocks may be pushed over younger ones and the apparent succession of the strata may be altered. It is this sort

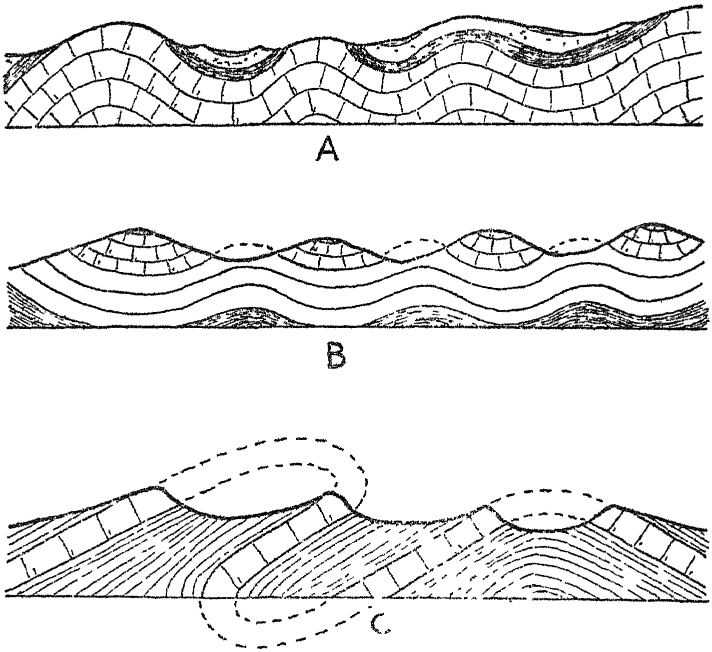

FIG 7a. TYPES OF FOLDING

A. Symmetrical folding, as in the Jura Mountains, where anticlines form the hills This is indicative of geological youth as denudation has not greatly modified the folded surface.

B Later stage in geological history of a folded region The anticlines have been worn away because rocks are in weakened condition consequent on being stretched, whereas synclines are harder and more resistant owing to rocks being compressed This type of mature scenery is well seen in the Appalachian Mountains of the U S.A.

C Asymmetric folding of alternate hard and soft beds gives rise, after denudation, to escarpments

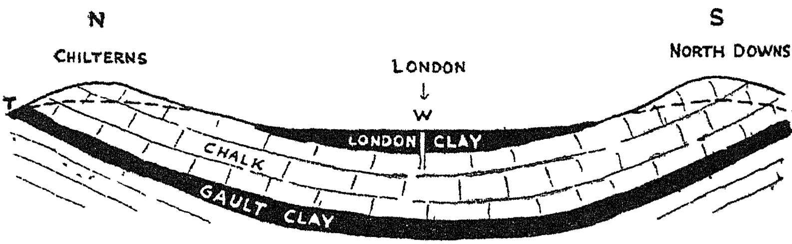

FIG. 7b. SECTION ACROSS THE LONDON BASIN

Porous Chalk lies between the impervious Gault Clay below and the London Clay above, and the whole series has been folded into a gentle syncline Rain falling on the Chilterns or North Downs percolates into the Chalk and saturates it to the level of the water-table (dotted line T—T). A boring, W, through the London Clay reaches water which flows up through pipe under pressure because surface level of well is below level T—T.

of thing that shows us that the rocks of the crust are not always arranged today in the chronological order in which they were originally formed. We thus need to have other means of dating the rocks in a relative way; one of these means is by the fossils found in the rocks, for it has been proved that each bed has its own characteristic fossil, or group of fossils, and the true order of succession can be worked out in relatively undisturbed rocks and made use of when more disturbed strata is investigated.

Folding and buckling are due to horizontal movements of the crust, but there are vertical movements, too, resulting from the internal contraction of the earth. These vertical movements are called faulting and result in the differential movement of rock masses (see Figs. 9 and 10). Stresses accumulate in the crust and eventually a break, or series of breaks, occurs. Blocks of the crust sink down, leaving others standing

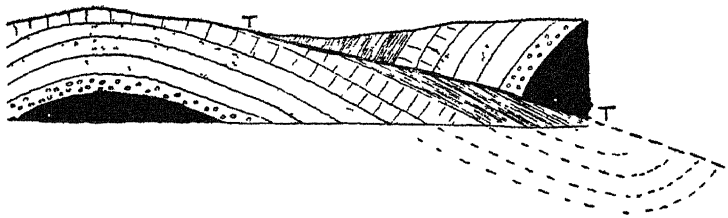

FIG 8 AN OVERTHRUST

Lateral pressure from right of diagram along thrust-plane, T—T, has forced older beds over newer ones Normal succession of the series is shown on the left of the diagram

higher. Many of the mountains of the south-western part of the United States are formed in this way, as are Table Mountain, in South Africa, and many of the "kloofs" of that country.

Valleys, too, can be formed by faulting, for example, a tract of land may be let down between parallel faults, and what is called a rift-valley results. It was in this way that the Great Rift Valley that runs from the Dead Sea to Africa was formed, and in which lie the Red Sea, and the great lakes of East Africa, Victoria Nyanza, Albert Nyanza, Tanganyika and Nyasa. The central valley of Scotland, part of the Eden Valley, near Carlisle, and that part of the Rhine Valley that lies between the Vosges and the Black Forest, are all rift-valleys.

It has been claimed that rift-valleys are formed by compression. Two more or less parallel blocks of the crust may be forced together by lateral movement and so force down a third and narrow block between them (see Fig. 11). This method of rift-valley formation links up with the conception of a contracting earth, for that implies a shortening of the crust and hence lateral movement.

A large excess of weight on any one part of the earth's surface seems to result in the depression, or subsidence, of that part of the crust, just as if

one has a number of blocks of wood of similar size and weight floating in water, the addition of a weight to any one of them would result in that block sinking somewhat in the water. The crust of the earth is said to be isostatically compensated, i.e. the weight of crust down to the base of the basaltic layer is the same for all blocks of unit surface area. In regions

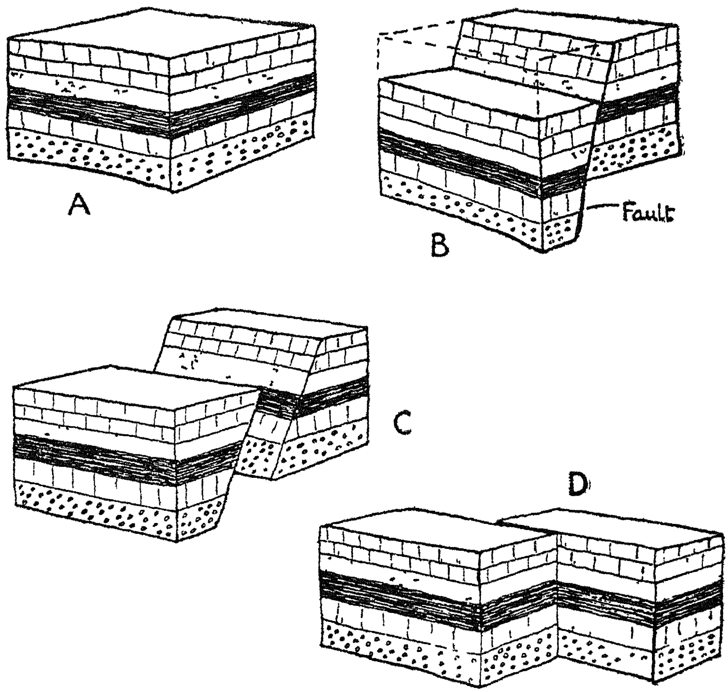

FIG 9 FAULTS

A Block of undisturbed sediments lying horizontally as originally deposited

B After simple faulting, causing vertical displacement of one mass relative to another

C After slip-faulting, i e movement of one rock mass relative to another involving vertical and horizontal movements

D After tear-faulting, i e when the relative displacement of the rock masses is almost entirely in the horizontal plane

where the land-level is high, therefore, the average density of the column of crustal matter beneath it is lower than in an area where the level of the land is not so high (see Fig. 3*b*). Any weight added to a region of the crust must, therefore, result in the depression of that area to some extent.

The usual way in which weight is added is by the laying down of deposits, but some parts of the crust are so delicately balanced that the extra weight added by the incoming of the tides along the shores will

produce a temporary subsidence, such is the case with Japan, where there is a measurable subsidence twice a day from this cause.

The extra weight added locally to the crust by the ice-sheets of an Ice Age, may produce subsidence of the crust. All around the south-western shores of Britain, for example, in the Gower peninsula of South

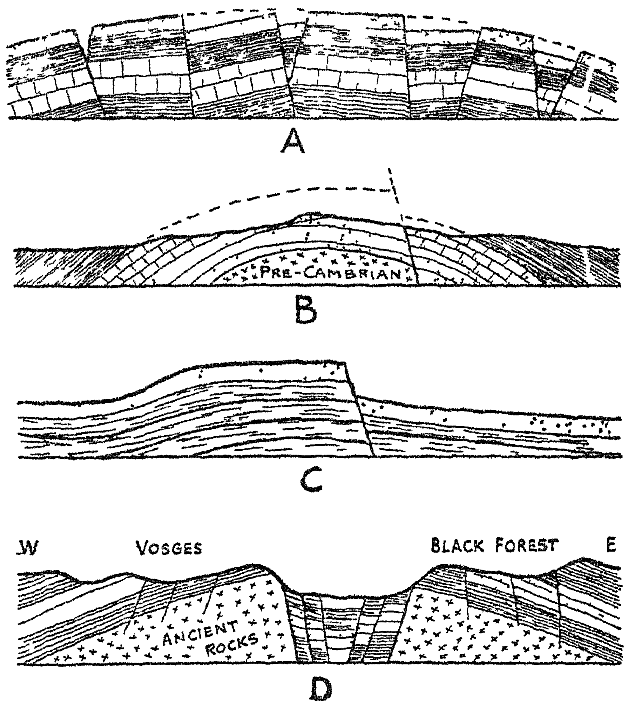

FIG 10 DIAGRAMS TO ILLUSTRATE FAULTING

A Block Mountains, formed by faulting of a huge anticline Examples are to be seen in Basin Range, U S A

B Uinta structure—faulting of an anticline, typical of Uinta Mountains, U S A

C Kaibab structure seen in the Kaibab Plateau, U S A

D Generalized section across the Rift Valley of the Lower Rhine The actual structure is much more complicated

Wales, and on the Devon coast near Torquay, there are to be found raised beaches, i e. deposits formed by the sea when the land was at a lower level than it is today.

Ancient sea-cliffs are also found some distance inland. It is believed that during the Pleistocene Ice Age, the extra weight of ice on Britain depressed the land by an amount which would bring the present level of the raised beaches to sea-level.

That changes of level have affected Britain in comparatively recent geological time is also shown by the occurrence of submerged forests, i.e. the remains of tree-stumps and other plant remains in the place of growth, in soil now covered by the waters of the sea, or of an estuary. Such forests have been found in Cheshire and Lincolnshire and along the shores of the Bristol Channel. In south-western England there is a close association of raised beaches and submerged forests, which suggests a rather complicated story of alternate elevation and depression of the land in that area.

One of the most famous examples of this sort of alternate movement is afforded by the Temple of Serapis, at Pozzuoli, near Naples. There, three marble pillars, about 40 feet high, are still standing. The first 12 feet of their surface is quite smooth, but the next nine feet are pitted with

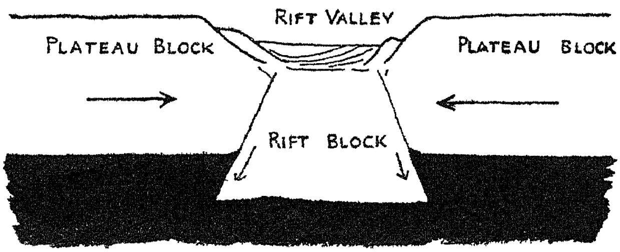

FIG 11 RIFT VALLEY BY COMPRESSION

Simplified section across Lake Albert region, Africa, to illustrate E J Wayland's hypothesis of rift-valley formation by lateral compression Valley block is held down by plateau blocks thrusting in direction of arrows

the borings of the shell-fish, *Lithodomus*, whilst for their remaining height, the pillars are smooth. It is supposed that some time after the building was erected, there was an eruption of Vesuvius which caused an accumulation of ash around the pillars to a height of 12 feet, the land then subsided some 20 feet, so that 9 feet of the pillars were under water and were attacked by the shell-fish. More recently still, elevation has brought the land level back to that it occupied when the pillars were erected.

Not only does this example show the alternation of movements, but it also shows the speed at which these movements may take place, for the whole series of events occurred within the historical period.

The alternation of vegetable remains (coal), which presupposes a land surface, with water-laid deposits of sand and clay, which is found in the Coal Measures, affords another good illustration of alternate elevation and subsidence. Numerous other illustrations of these oscillatory movement that have affected and still affect the crust of the earth, could be cited from the record of the rocks.

Another constructive process that helps to build up the land areas is that of volcanic activity. Each normal eruption of a volcano adds some material to the surface. A few figures will show this. The greatest active volcano in the world is Mauna Loa, in Hawaii; this reaches an altitude of 13,760 feet, and lava streams from its crater reach out for 50 miles. Thus it has produced a cone containing some 46,000 cubic miles of material. The volcano of Mauna Kea, in the same island, is now extinct, but it has a cone of 13,805 feet in height. The well-known Etna, in Sicily, covers an area of some 500 square miles, and is 10,755 feet high.

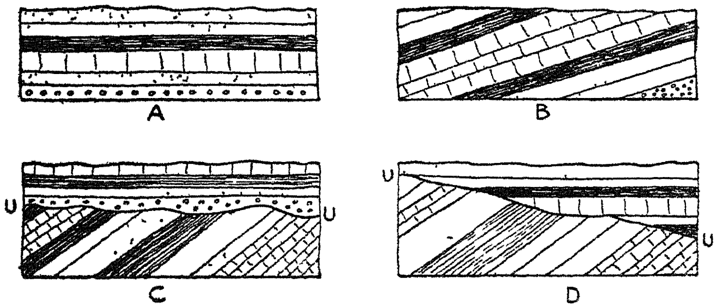

FIG 12 DIAGRAMS ILLUSTRATING ROCK STRUCTURES

A Horizontal beds as deposited under water

B Beds after tilting, they are then said to dip The angle made with the horizontal is called the angle of dip

C Upper series laid down on worn edges of B The two series are not conformable and the plane of junction of the two series is called an unconformity

D Another type of unconformity In the upper series each succeeding bed extends farther laterally than the underlying bed, this is called overlap

If we assume that the cone is symmetrical, then it contains approximately 6,000 cubic miles of ejected material.

There are many hundreds of still active volcanoes, and many more only recently extinct. It can be seen, therefore, that the total mass of material added to the outer surface of the earth by volcanic action is very considerable and helps, to some extent, to compensate for that denuded away by other agencies. It should be remembered, too, that many of the islands of the Pacific Ocean are of volcanic origin, they are the cones of submarine volcanoes which rise from the sea-floor and reach above the surface of the water, and so form isolated islands. Some, whose summits do not reach the water surface, attain a level sufficiently near it for the

establishment of coral polypes, and these organisms may construct an organically-formed mass which emerges from the ocean as an atoll, or coral-island.

Coral Islands

Something is said later of the changes effected on the surface of the earth by the action of man, and other organisms, but since coral-islands have been mentioned here, it may not be out of place to say a word about them under this chapter heading.

Corals have helped to build up reefs and islands, and so changed the face of the oceans, in the tropical regions of the earth. Where submarine platforms or volcanoes occur at a level beneath the surface at which corals can exist, and where there is no great accumulation of sediment, these marine creatures establish themselves and gradually build up a mass of calcareous rock, formed of their skeletons, until the water-surface is attained. Sand and other detritus brought by the ocean currents collect on the coral-rock. Branches of trees are washed ashore, birds bring seeds in their beaks, and, in time, vegetation springs up on the atolls and islands formed by these small creatures.

Not only do corals help in building up new lands, but they also assist in protecting old ones from erosion. The Great Barrier Reef of Australia, which runs for 1,200 miles along the eastern coasts of that continent, slightly off-shore, helps in protecting the coast from the erosive action of the ocean tides, whilst in the lagoons that lie between the reefs and the shore, sediment slowly accumulates and will, in time, form flats.

As we consider the various factors at work in changing the face of Mother Earth, we may say truly, with Tennyson:

> There rolls the deep where grew the tree,
> O Earth, what changes hast thou seen,
> There, where the long street roars, hath been
> The stillness of the central sea.
> The hills are shadows, and they flow
> From form to form, and nothing stands.

But great though the changes are that have been effected by the forces and processes so far mentioned, there is yet another factor which, if some geologists are right in their theories, has produced even more marked changes in the face of the earth.

Continental Drift

This factor is the drift of the continents, a theory usually associated with the name of the German scientist, Dr. Albert Wegener. He was

not, however, the first to make the suggestion that the great continental masses do not always remain in the same positions, through geological time, nor is he the sole modern exponent of the theory.

At first sight, it may seem rather a fantastic idea that the continents can wander and so form fresh groupings, yet that is the suggestion, and there is an increasing body of evidence to support the view which also serves to explain certain observed facts (for example, the Gondwana glaciation referred to below) better than any other theory does.

Anyone who glances at a map of the Atlantic Ocean cannot fail to be struck by the great similarity in shapes between the seaward eastern bulge of South America and the inward curve of the west African coastline, a similarity noted three centuries ago by Francis Bacon. It almost seems as though one could fit the Brazilian bulge into the Gulf of Guinea. Advocates of the Drift Theory maintain that, in fact, the two land masses were once joined together. But geographical shape is not conclusive evidence. The outlines of the continents as shown on the usual maps do not truly represent the actual edges of the continental masses, which are the edges of the continental shelves. These latter are shelves of varying width bordering the land masses and lying beneath only comparatively shallow water. In some cases these shelves are wide, as for example the western European one whose edge lies out to the west of the British Isles which are really higher portions of the shelf lying above sea-level.

But there is still better evidence for the former connection of the great land-masses of the southern hemisphere than correspondence of geographical outline. The same type of rocks occur in Africa and in South America, these are similar in nature and in their fossil content. Farther east in peninsular India similar rocks and fossils are also found. One striking illustration is the fossil flora of the rocks of Permo-Carboniferous age in all three localities. This flora is unknown elsewhere in the world. Plants cannot migrate across great stretches of water so that there must have been a former land-connection of some sort between the three areas. The old idea was that narrow land-bridges existed that have since foundered, but if this were true, there would be some traces of such ridges on the ocean floors between the land-masses and there would also be traces of faulting on a large scale. Such are not found.

The Drift Theory explains these correspondences far better and also other facts For not only do the rocks agree, their structures agree too. If the continents of South America and Africa are fitted together as suggested, it is seen that lines of earth-movement in the one continent join up with lines of similar movement in the other fairly accurately.

Perhaps even more remarkable, and certainly most easy of explanation on the Drift Theory, is the fact that the Permo-Carboniferous rocks of all three areas contain evidence attesting to the existence of an Ice Age during that period of geological time. And, be it noted, that was a period when tropical conditions existed in the British and North European area as the deposits of the Coal Measures (of similar age) bear witness. The

three areas mentioned all lie, today, close to the Equator, and the best explanation for the then existence of an Ice Age in them is that they then formed part of a great land-mass, parts of which rose to considerable altitudes and so could form gathering-grounds for ice-sheets and glaciers.

This great land-mass probably lay farther south than those areas do today and contained the Antarctic region of the period. Confirmation of this view is obtained by a study of rocks of Permo-Carboniferous age elsewhere. It is found that the rocks of that age in Scotland contain laterites (see Chapter VIII), as do also those of the United States, and laterites are soils which are formed under tropical conditions.

There is also evidence of glacial action in Alaska at the same time, and that would lie within the northern polar region on the above position for the south polar region. All these facts fall into line with the theory that the south pole then lay within Gondwanaland, as the great land-mass now broken up into South America, Africa, peninsular India, Australasia and Antarctica, is called.

Wegener used another line of evidence in his original presentation of the theory, and although it has since been discredited it still crops up in popular accounts of the theory and therefore needs mention. He believed that a comparison of longitude measurements for Greenland showed a westward drift of that land. This supposed drift was of the order of a few feet a century, the period over which the measurements he used were taken. Naturally if there were such a drift and it were continued overlong periods of geological time the actual movement would amount to many hundreds of miles. More accurate determinations of the longitude of Greenland have now shown that that there is no such drift taking place, at least at the present day.

The Drift Theory postulates, as briefly noted above (and illustrated in Fig. 13), that the land-masses of the Americas were formerly joined to Eurasia, and that they have subsequently moved westwards, whilst Australia, once united with south-east Africa, has moved away to the south-east, and peninsular India has drifted to the north-east and so pushed against the great ancient land-mass of central Asia, crumpling the deposits and rocks between into folds which resulted in the formation of the Himalayas. Antarctica moved away to the south. Wegener graphically described these movements as the *Pohlflucht*, or "flight to the poles".

These movements would also give an explanation for certain other tectonic features already noted, namely the occurrence of great fold-mountains all along the western side of the Americas, for as those continental blocks moved westwards they would tend to buckle up the rocks on their leading-edges. The further fact that the African continent contains no fold-mountains (with the exception of the Atlas Mountains which geologically belong to Europe) and the continent is much block-faulted and rifted is also suggestive of the truth of the Drift Theory, for such types of earth-movement attest to crustal tension and tearing.

Dr. du Toit, a famous South African geologist, has collected a whole mass of evidence on the matter of the Gondwana glaciation and is a firm believer in some form of continental drift. He differs from Wegener in the way that he arranges the continental masses before disruption began. Evidence from fossil and living plants collected by Professor D. H. Campbell, of Stanford University, California, and published in 1943, strongly supports du Toit's view that there were, originally, two great sial masses, or continents, each of which was separate from the other, and each of which has subsequently become disrupted.

The two masses were Gondwanaland, or the southern mass, and Laurasia (North America and Eurasia, excluding India), the northern mass.

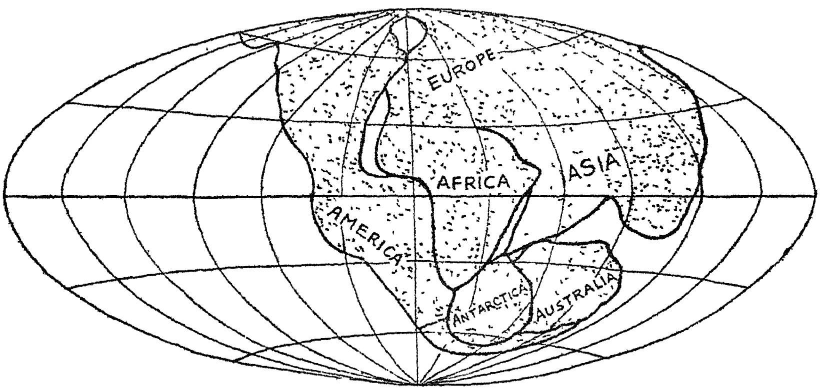

FIG 13. WEGENER'S THEORY

Wegener's theoretical reconstruction of continental distribution during Carboniferous times. Africa is shown in its present position on the globe for the sake of clarity. Probably the whole land mass lay farther to the south and enclosed the south polar region of the time.

Between them lay a great latitudinal sea, called Tethys, of which the Mediterranean is a much shrunken remnant. The former westard extension of Tethys is now represented by part of the Atlantic Ocean and the eastward extension by the sediments which, laid down in it whilst still a sea, have now been folded into the Himalayan Chain.

Professor Campbell argues that a comparison of the existing and fossil floras of the northern and southern hemispheres makes it clear that the two regions were completely separate until at least the end of the Mesozoic Era, and that North America and Eurasia have always been more or less intimately connected. This latter fact is borne out by other fossil evidence extending back as far as the Cambrian Period.

Campbell also maintains that the relations between the plant genera, and even the species of West Africa and Brazil, and Chile and New

Zealand are so close that former land connections must be assumed.* The almost complete absence from the southern continents of boreal trees such as *Pinaceae*, *Saliceae* (willows), *Fagaceae* and *Magnolaceae*, and the absence in the northern hemisphere of many austral families of plants, such as *Myrtaceae* and *Protocaceae* and the coniferous *Araucaria* and *Podocarpus* is evidence, so Campbell argues, of the complete separation of the northern and southern land-masses from at least late Paleozoic to late Mesozoic times and thus confirms du Toit's hypothesis.

When the first connections between the two masses were first established is not yet clear. One slender clue is afforded by the fauna of Australia, which is characterized by the many variants of marsupials, or pouched animals. These mammals, like all others first evolved in Eurasia and then migrated outwards into other continents with which there was land connection. Marsupials evolved in the later Mesozoic Era, so that Australia must have been united with the northern continent about that time and then cut off, since the later mammals that evolved in the Tertiary Period did not reach the southern Pacific continent.

Some confirmation of the Drift Theory is also forthcoming from seismic and mountain-building phenomena in the past and present. It has already been stated that the majority of present-day earthquakes take place along the same two belts along which the Tertiary mountain-folding occurred, two belts which are, therefore, lines of crustal weakness, weakness which may have been caused by continental movement. One of these belts encloses the lands which are presumed to have once formed Gondwanaland, the other encloses Laurasia.

Additional structural evidence in favour of du Toit's view is afforded by a comparison of the coasts of the North and South Atlantic Oceans, in the former case there is much faulting and fracturing, in the latter the coasts are more of a folded structure. This would be explicable on the hypothesis that South America drifted away from Africa and North America and Eurasia became separated by block-faulting and if this occurred at the close of the Mesozoic and in the early Tertiary it would link up with the great outpourings of lavas from fissure eruptions that characterize the Eocene Period in the western islands of Scotland, for fissure-eruptions and block-faulting are often found to be associated. That faulting would have caused the break-up of the ancient land-mass that linked Europe and North America and of which Iceland and Greenland are the remnants left above sea-level.

The questions may now be asked, how can continents drift, and in what do they drift? But first let it be noted that although all geologists

* This similarity is also evidenced by other forms of life. A few examples must suffice here. A species of freshwater worm, *Phreodrilus*, occurs in mountain lakes in New Zealand, Tasmania, Australia, South Africa, Patagonia and the Falkland Islands. A distinctive subfamily of earwigs is found in the Andes and on the banks of the Caledon River, in the Orange Free State. The same sort of thing is to be noted amongst the fauna of the northern hemisphere. There is in the West Indies and Galapagos, a genus of grasshopper which is also found in the arid districts of Eurasia. These and many other examples all point to former land connections.

are not yet satisfied with either of the restorations of the continents suggested above, the great majority of them do believe that some form of continental movement on a greater or lesser scale has taken place. We have already seen, in an earlier chapter, that the outer crust of the earth is made up of two layers or shells, the one discontinuous and lighter than the underlying one on and in which it rests. The continents may thus be pictured as gigantic "rafts" floating in the basic layer, in the same way as ice-bergs float in the sea.

The presumed movements of the continents would explain many facts about earth structure, and the distribution of fossil types in areas

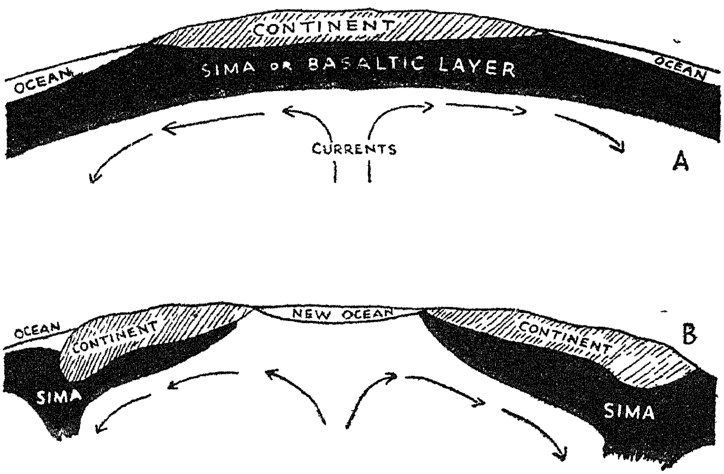

FIG. 14. THEORY FOR CONTINENTAL DRIFT (after Dr. Arthur Holmes).

A. Early stage—thermal currents just commencing
B. Later stage—after thermal currents have been in action for a considerable time.

now widely separated. The great difficulty is to account for the movements in varied directions. This means that they cannot be due to some constant factor like the rotation of the earth, or the gravitational attraction of the sun and moon; the cause of the movements must be within the earth itself. Various theories have been suggested but they are technical and are based on theoretical considerations. There is one exception, though, which merits a short description because it can be fairly easily understood and can be, to some extent, experimentally verified.

This is the suggestion that there are, within the earth, convection currents due to the increasing temperature with increasing depth. (See Fig. 14.) If the currents ascended under a continental block, or blocks, they would tend to drag the superincumbent mass apart as they spread out horizontally under it; if the currents diverged they would create great

tensions in the block which might conceivably break up and broken masses would drift in varying directions. If, on the other hand, currents converged under a continental block there would be a state of compression produced and buckling and folding might ensue, and fold-mountains be produced.

The convection currents could be caused either by heat rising from the depths of the earth, or by the unequal distribution of radio-active material (a source of heat) within the sub-crustal material. Experiments carried out in America by D. Griggs, seem to lend credence to the theory. He used materials which bore a relationship to each of the layers of the crust and produced currents in the sub-crustal equivalent, not by heat,

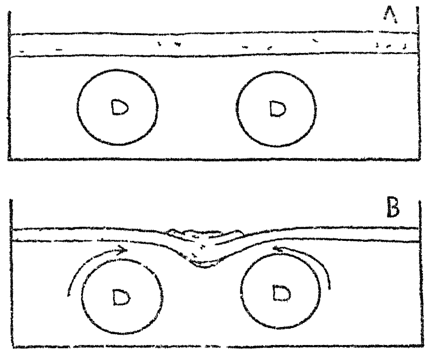

FIG. 15. GRIGGS'S EXPERIMENT

A. Apparatus before rotation of drums DD.

B. Apparatus after drums DD have been rotated in direction of arrows, i.e. converging currents cause piling up of crustal layer.

but by revolving drums whose direction of rotation and speed could be controlled. Figure 15 illustrates the results obtained.

In the actual earth the currents produced by heat differences would be far more complicated and the crustal movements created by them would be far from simple. The currents would also vary in strength and direction —at times there might be no movement, thus continental drift and mountain building is not a continuous process. This accords with the observed facts; there do appear to have been periods when earth-movements were very violent and periods of quiesence.

Our present state of knowledge may be briefly summarized—the theory of continental drift, whilst not without difficulties, is by far the best explanation for the many problems met with as we study the distribution of animal remains, of Ice Ages, and land and sea at the present and in the geological past. The main opposition to the theory comes from those who cannot see what forces could produce the drift but the convection-current

theory may solve the problem although it has been criticized on the ground that it is difficult to see how the currents would remain in the same place for a long enough time for considerable drift to occur. Further knowledge of the earth's interior is obviously needed.

But despite all criticisms and objections one cannot help feeling that Galileo's remark about the earth still holds good for the sial, "Still it moves". The upshot of the matter is that the surface of the earth is now realized to be not so stable as it was once believed to be, there is change. Could we have a map of the world in, let us say, Carboniferous times it would be very different from one made today.

CHAPTER V

EARTH'S CHANGING FACE: (2) IN THE PAST

NOTE.—For those unfamiliar with the names given to the various geological systems, and their order, it will be necessary to consult the table on p. 87 from time to time, and the last paragraphs of Chapter III.

IF it were possible to travel backwards through time and view the surface of Mother Earth in past ages, we should find—as might be expected in view of the foregoing—that there would be many differences to be observed in the arrangement and outlines of the land-masses, and variations in climatic conditions. Reconstructions of ancient coastlines are sometimes attempted and drawn in what are called paleographic maps, but such maps are, for various reasons, mainly guesswork, at least as regards details. How does one set about reconstructing the past geographies? A knowledge of deposits, their nature and structure, the way in which they change when traced across country, the fossils they contain, all these things are straws in the wind and help to guide us.

The presence of a conglomerate bed—that is, a cemented mass of pebbles—indicates the proximity of an ancient shore-line to the site of the deposit, since such deposits are laid down close to the shore. The nature of the pebbles may indicate the older rocks from which they were eroded. The tracing of a given bed over a wide area may show considerable variations in it which may indicate the variations in the sea-floor at the time. If there is a break in the bed, it may show the former presence of a land ridge, just as fine-grained deposits of certain kinds indicate deep water at the time of deposition. Beds of pure limestone are indicative of deep clear water, also, as for example the chalk.

The sand grains in desert and sand are worn in a different way from those of the sea-shore, and that difference can be detected in ancient sands so that the former presence of deserts can be inferred; this can often be corroborated by finding salt deposits associated with the sands, for such deposits are usually formed as a result of evaporation from desert lakes.

Something has already been said of the value of fossils in indicating past conditions of climate. Fossils are usually marine in origin but despite that limitation they can be very useful; for example, it is possible to tell whether a deposit was laid down in the sea or in fresh water, and an alternation of marine and freshwater fossils may indicate changes in geography which had not been suspected from the other features of the deposits. It had usually been assumed, for instance, that the swamps, in which grew the vegetation that became the coal of the Coal Measures, were adjacent to the sea which invaded the areas from time to time, but

recent work on the fossils of South Wales and elsewhere has shown that some beds contain freshwater types; this means that sometimes the swampy areas became cut off from the main sea of the period.

Geographies of the Past

But despite all these ways of reading the record of the rocks, there are many limitations to the work of reconstructing the past geography. We can only study these rocks which are accessible on the present land-surfaces, and they represent only a fraction of the total deposits of the crust. We can only draw broad and indefinite boundaries between land and water and cannot fill in all those smaller features, such as capes and bays and off-shore islands, which though small make a coastline distinctive and interesting.

There has been in the past, too, a tendency to insert into paleographic maps those features called "land-bridges", narrow tongues or isthmuses of land linking those areas where there has been similarity of terrestrial flora and fauna in the past, but which are not separated by water. For example, in Carboniferous times, there was a characteristic and distinctive flora or plant assemblage, existent in South America, South Africa and India, and older attempts at reconstruction showed "land-bridges" between these regions. Such hypothetical connection might explain the distribution of living things which could not cross oceans, but today there is an alternative explanation, namely the hypothesis of Continental Drift, for which there is other evidence, too.

Despite all these drawbacks, and the fact that there are great tracts of the land areas still to be geologically studied in detail, it is possible to draw paleographic maps with fair accuracy of such well studied areas as the British Isles and North America, and to describe the changing face of Mother Earth during the past.* It may be of interest to describe briefly the history first of the British area, and then of North America, in order to show the many changes in topography and climate that have occurred, and then to give a few other general examples in lesser detail. To that task we now turn.

Geological History of British Area

We cannot be very definite about the condition of the British area during the pre-Cambrian because the deposits of that age are very much metamorphosed as a rule. They contain no fossils, and rocks in one region are therefore difficult to correlate with those in another. All we need say here is that pre-Cambrian times drew to a close with much land

* *The Building of the British Isles*, by Jukes-Brown, contains some interesting reconstructions of the British area during the various geological periods.

in our area. But during the succeeding Cambrian Period the sea invaded parts of the area, including North and West Scotland, North and South Wales and parts of England.

Anglesey was part of a great land-mass that extended far away to the west, and the eastern coastline of which trended north-east and south-west through Carnarvon; there was another land-mass to the south of Pembrokeshire, which may have been connected with another land area farther south and which contained what is now the Lizard area of Cornwall, the Channel Islands, Brittany and that part of the western English Channel that lies between them.

Subsidence of the land continued throughout the period, with an increase of sea in the Franco-British area, with parts of Brittany forming islands in it, and the land west of Wales persisting. The fossils of the Upper Cambrian rocks of North Wales and those from beds of similar age in Scotland are very different, whereas those from Scotland are very similar to those of the same age from North America. These fossils are all of shallow-water type, living in coastal waters, and it is therefore presumed that there then existed a land connection between North Britain and North America, the southern shore of a continent which persisted in the North Atlantic during many succeeding geological periods, and that there was a deep sea between the North Scotland area and the Welsh area.

The Ordovician period followed and there still existed the Atlantic continent* away to the north, and the land to the west of Wales with a coastline still running N.E.-S.W. from Northern Ireland across Central Scotland, and receding and advancing with alternating movements of the crust. Most of the British area was under the sea, with local variations in sea-level. During this period there was much volcanic activity in North Wales, Lake District and Scotland, and great masses of lava and ashes were ejected from numerous volcanoes.

Silurian times were to see a great change in the British area, earth-movements elevated much of the region which was covered with localized shallow seas whose shore-lines changed positions as the crust oscillated. The old Ordovician coastline to the west was maintained, and the land mass became extended until it included what is now the Highlands and Scandinavian areas, whilst a tongue of land projected across central England, and of which the Malverns and the Longmynd Hills probably formed part. Slow gradual upheaval of the whole area continued during the period so that by the time the Devonian period began most of Britain was land, with the sea away to the south. Only in Devon do we find

* This Atlantic continent is not to be confused with the legendary Atlantis, for which there is no real geological evidence The continent referred to above disappeared before the advent of man on the earth, being disrupted by earth-movements early in the Tertiary Era. There is no evidence for the existence of a continent in mid-Atlantic during the time that man has been on the earth, as the supporters of the Atlantean myth hold to be the case. The foundering of such a continent within comparatively recent times, geologically, would have perceptibly affected the neighbouring coasts—no such effects are known, nor does exploration of the ocean floor endorse the belief.

deposits of marine origin of this age, for example the limestones of Torquay which contain many fossil corals, reef-builders, which seems to indicate tropical conditions in the area.

The other deposits of the period were sandstones laid down on the land surface or in the lakes which lay in various parts, including the Hereford and Welsh border area, and North and Central Scotland. Rivers flowing into these lakes brought in much sandy sediment. The whole of the British area formed part of a large continent which included northern Europe and extended westwards across the North Atlantic region.

With the close of the Devonian Period, subsidence slowly set in and the outer and lower parts of the northern continent became gradually submerged during the succeeding Carboniferous period. The sea covered most of central and southern England, Ireland, northern England and southern Scotland, but there were land areas to the west, south-west and north-west. Much of what is now Wales and the Irish Sea was also land—St. George's Land, it is sometimes named.

In the middle of the Carboniferous Period, land movements resulted in a shallowing and lessening of the seas, into which great rivers poured masses of sand, now forming the Millstone Grit of the Pennines and South Wales. All through the later part of the period there were minor oscillations of the crust, resulting in the conditions necessary for the formation of the coal-seams, which are the fossilized remains of abundant plant life. It seems as though these plants grew in low-lying and swampy ground close to the shore, something like the conditions in the Floridan swamps of today, and that from time to time, subsidence was sufficient for the sea to invade and so kill the vegetation, then came a recession of the salt waters and another crop of plants, and so the whole cycle began again. Each coal-seam represents a time when the area was land and plants could thrive, and in some coal-fields there are twenty or more seams of varying thicknesses.

The succeeding Permian Period was one of great earth-movements resulting in the elevation of the whole British area into land, on whose surface there were a few salt lakes, one of which covered parts of the Midlands, thus producing a landscape something akin to that which now surrounds the Caspian Sea. The land was desert and may have been tropical. The earth-movements resulted in the formation of many fold-mountains, for example the Pennine Chain and the Mendip Hills came into being at this time, the coal-beds and their associated deposits were folded into synclines or basins, and this resulted in the separation of areas that had formerly been continuous.

The coal-fields of South Wales, the Forest of Dean and the Bristol area, for example, were once continuous, at least the original deposits were, then came the post-Carboniferous folding and they became isolated basins. As a consequence of these movements most of the British area remained above sea-level during the Triassic Period, the land still being desert, with salt-lakes dotted here and there, notably in what is now Cheshire, hence

the salt deposits of that region today. Slow and gradual subsidence ensued as the period drew on and larger lakes were formed which lapped around the older folded rocks that formed ridges and islands, for example, the Mendips and the Quantocks, around the flank of which are found conglomerates of the period, thus indicating that they were shores then. Away to the east, in what is now Germany, lay the open sea, in which was deposited the limestones of the period that are unrepresented in Britain.

But not for much longer was the British area to be land, submergence continued as the Jurassic Period began, the erstwhile lakes became gulfs and bays and seas, and gradually the waters of the open ocean broke in and covered much of the area, with the exception of the older mountains which remained as islands throughout much of the period. The Jurassic sea was fairly shallow and variable for there were minor oscillations of the crust all through the period, thus it is that the deposits of the time are very varied. The great Atlantic continent still persisted away to the north and north-west. As the period drew to a close, slight emergence of the land took place and the seas retreated south and east until only the extreme southern part of Britain remained beneath its waters.

By the beginning of Cretaceous times, most of the area was again land except for a large lake which covered what is now the Weald and which extended eastwards across Belgium and parts of France. There was also a long narrow gulf of water lying across eastern Yorkshire and forming part of a sea that lay to the east, but as the period passed there came increasing subsidence until almost the whole of the British area lay beneath the sea, that deepish clear sea in which the Chalk was deposited and which, as will be seen below, stretched over most of Europe. One gulf of the sea stretched out across northern Ireland and well beyond the present western coastline of Ulster, to wash the shores of the northern continent. One or two of the higher mountains of Wales may have stood out as islands from the Cretaceous sea, for example, the Plynlimmon mass and Snowdonia, and the Highlands of Scotland may also have been land. Emergence of the land took place in Britain before the period ended, so that much of our area was once again above the sea when the Tertiary Era opened.

The Eocene Period was mainly a terrestrial one for our area. There was a great gulf lying between Britain and Scandinavia and extending down over Belgium, an arm of which covered the London area, and another sea lay over Hampshire and the Isle of Wight and extended maybe as far eastwards as the Paris Basin. The fossils of the Eocene, many of which are similar to forms still living, attest to the tropical climate that then persisted in the British area; palms and other plants that now thrive in southern seas were growing around the London and Hampshire waters, whilst in them lived reptiles and shell-fish associated with much warmer lands today.

Much the same arrangement of land and sea persisted through the succeeding Oligocene Period, although the sea-covered area was becoming

smaller, for earth-movements on a grand scale were beginning, movements which reached their maximum in the Miocene but which have not yet entirely died down.

Somewhere about this time there occurred the disruption and foundering of much of the ancient northern continent, accompanied by great outpourings of fissure-lavas along the western coasts of Scotland, whilst farther south the folding was beginning that was to form the great mountain chains of the Alpine-Himalayan system. The Cretaceous and Jurassic deposits of the southern part of England felt some effects of this folding and were buckled into the London Basin syncline, the Wealden anticline and the Hampshire and Isle of Wight folds. All the British area, including what are now the North Sea and English Channel, was land, with one smallish lake in Devon, and great rivers running across the plains between Britain and France and Britain and north-west Europe, and emptying into an Atlantic that lay well away to the west. The climate was slowly changing for the worse as the Tertiary passed and the succeeding Pliocene beds contain fossils of forms that are associated with cold temperate climes today. Slight changes in the level of land and sea during the Pliocene turned south-west England into an archipelago, 400 feet lower than at present, with the granite tors standing out as islands. Elsewhere conditions were much as in the preceding period, so were they during the Pleistocene Period that followed so far as geography went, but there was a great climatic change, the increasing cold culminated in the Glacial Period.

The Great Ice Age

The whole of Britain north of a line drawn from the mouth of the Thames to the mouth of the Severn became covered with a series of glaciers and ice-sheets, from which the higher hills would have stood out as numataks; in fact, the country must have closely resembled Greenland of today. To the south of the edge of the ice it must have been very cold, with the surface soil frozen, so that streams could flow over the limestone hills and slopes (normally limestone is porous and does not bear surface streams) so wearing valleys which still exist in many cases as dry-valleys, for the streams that carved them have now gone. Many such valleys are to be seen in the Chalk hills of southern England.

The ice-sheets were not constant, there were warmer intervals when they retreated, then they came back again; there were several of these warm periods in Britain as elsewhere in northern Europe which, too, was covered with ice, as was much of North America. Many theories have been put forward to explain the Ice Age but since none of them is entirely satisfactory it is unnecessary to give them in this book. It will be obvious from what has been said elsewhere that this is not the only ice age that has occurred in the past, the Gondwanaland one has been mentioned,

and there have been others at different places in different geological periods.

Gradually the climate became more temperate, the glaciers shrunk, animals and men began to migrate into the British area, by then very much as it is today, but with land connections across the North Sea and English Channel, both of which areas were broad plains across which large rivers wandered. These land connections persisted until the end of the Paleolithic or Old Stone Age—some 10,000 years ago—when the slow subsidence that had been going on for some time resulted in the Atlantic waters flooding the river-plains and completely separating off the British Isles from the continent.

Since that time there have been slight oscillatory movements of the crust in various places, but no marked geographical changes in the British area. The usual agents of sub-aerial denudation have been gradually smoothing the rougher outlines, the climate has been slowly becoming warmer, and today the edge of the permanent polar ice is far away to the north of our area; plant and animal life characteristic of more temperate latitudes has gradually established itself in our country, but great sheets of glacial drift, scratched rocks and erratics* all attest to the former presence of the ice-sheet.

The foregoing account has of necessity been short and generalized; different authorities would probably differ in details, but in general the story is agreed on. The other area whose past history has been well worked out and which it is proposed to describe is North America, but here again, only a generalized account is given. In such a large area there are still bound to be some regions where the rocks have not been studied in detail and so there will be emendations to be made as new knowledge comes in, but our purpose here is to show that there have been changes, and that the geography of the present is not necessarily that of the past.

Geological History of North America

The paleographical map of North America (Fig. 16) shows an approximate picture of that area in Paleozoic times, several large islands rising from seas in which deposits were being laid down that were later to be elevated and folded to form the present land-mass. It will be noted that the Canadian or Laurentian Shield of pre-Cambrian rocks is above water and therefore was subject to sub-aerial denudation. A short sketch

* Erratics are rocks which lie on the surface of the land and which do not belong to the local strata, but which were carried to their present position by glaciers, and deposited when the ice melted. Study of such erratics helps us to trace out the direction in which the former glaciers moved, for example, if rocks only found in the Pennines are found as erratics on the Midland Plain then it is fair to assume that a glacier moved from the Pennines out on to that part of the Midland Plain where the erratics are found. It is in this way that we know glaciers from Scandinavia flowed across the North Sea area and reached the east coasts of Britain.

is given below of the changes that have occurred in the area during post-pre-Cambrian times. Little is as yet known of the shape and size of the land-mass at the beginning of Cambrian times, but it was probably larger than at present, and may have been joined to north-west Europe.

During Cambrian times downward folding took place and allowed an invasion of the sea along two narrow tracts, so forming the Cordilleran and Appalachian troughs or geosynclines. These two regions of deposition persisted, with variations, for many geological periods. Oscillation of the land resulted in more submergence of land during Middle Cambrian times and a withdrawal of the water towards the close of the period and the succeeding early Ordovician Period, but in the middle of the latter period there was another downwarping of the land and water covered much of what is now the eastern United States and south-east Canada, although this sea was not connected with the Atlantic, there being a land ridge between. Eventually this sea spread northwards until it joined with the Arctic Ocean. The Rocky Mountain area was an area of deposition all through the period. At the close of the Ordovician, a series of earth-movements uplifted and folded the deposits in the Maritime Provinces of Canada into mountains, but did not affect the deposits of the interior.

In early Silurian times the seas were more local and of lesser extent than in the Ordovician, but gradually they invaded the land until by the middle of the period they attained their maximum extension, with most of the continent under water, and on the floor of this sea were deposited the calcareous deposits that later became the famous limestones of Niagara.

North America at this time must have presented the appearance of a gigantic archipelago. As the period drew to a close, elevation of the land set in and by the end of it most of the continent was land again. Lower Devonian times saw the invasion of the sea along narrow troughs in the Acadian region of Canada, in the Appalachians and the Rockies, and another flood also advanced northwards from the Gulf of Mexico. Gradually the land sunk still more, the seas spread, the waters advancing from the south and east met and spread north over a great area of the interior of the continent. There was, at the same time, a considerable expansion of the Cordilleran sea. The end of the period brought gradual elevation of the land and consequent draining away of the seas, and in the Acadian region there were considerable earth-movements which folded and twisted the rocks. This was accompanied by igneous activity in New Brunswick and Quebec.

When the Carboniferous Period began, most of the continent was land, but slowly a marine transgression occurred, waters from the south spreading over a large area in the Mississippi Basin and into Michigan, Ohio and Pennsylvania. The Rocky Mountain or Cordilleran geosyncline was also flooded again at the same time. The sea retreated by Middle Carboniferous times and the Upper Carboniferous period was one in which

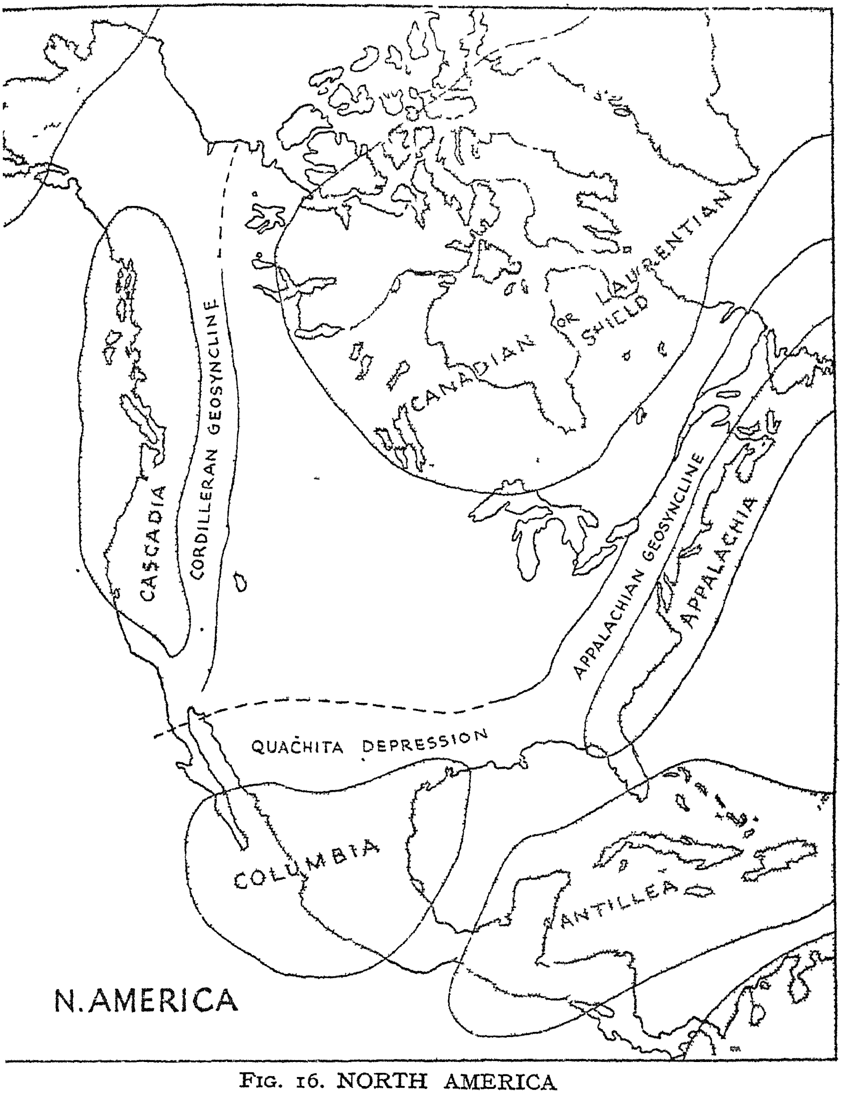

FIG. 16. NORTH AMERICA

eneralized paleographical map of the area in Paleozoic times to show distribution
f land-masses and geosynclines (areas of persistent deposition). Deposits in the
tter were later folded to form the present mountain chains of the continent.

most of eastern North America was affected by slight crustal movements and invasions of shallow seas into more or less land-locked basins wherein were deposited the great accumulations of plant remains that later became the coal-seams of the Appalachians and Pennsylvania.

In the western parts of the continent the earth-movements were more pronounced and for the first time for long ages the sea invaded the flank of the old land-mass that lay to the west of the Rocky Mountain geosyncline. The Permian period that followed was one of vulcanicity and earth-movement, the Appalachians were elevated in the east and most of the continent became land, with the eastern coast farther out to sea than it is today. The eastern parts were land all through the Triassic Period, except for narrow troughs and valleys, mainly formed by faulting, but in the west, the waters of the Pacific advanced over a wide area, whilst there was considerable igneous activity, and pronounced elevation at the close of the period.

Most of the continent remained above sea-level during the Jurassic. Period, and was, therefore, subjected to much sub-aerial denudation, There was, however, a marine invasion in the early part of the period over parts of the northern Pacific coast and into California, Oregon and Nevada. Elevation at the close of the period produced the Cascade and other ranges. This event was accompanied by the greatest uprising of molten magmas since pre-Cambrian times. From Lower California to Alaska, the pre-existing rocks were torn open and invaded by enormous uprisings of acidic magma which later cooled and crystallized to form granitic masses which now form whole mountain ranges in the Sierra Nevadas and the Coast Range of British Columbia.

The regions which now form Mexico, Central America and the southwestern United States were invaded by the sea during Lower Cretaceous times, and there were also invasions by the sea along the Pacific coasts. During the latter part of the period, the Upper Cretaceous, there was much marine transgression along the eastern coastline of the United States, around the Gulf of Mexico and a wide strip of the Pacific coast, whilst depression of the interior continental region caused marine waters to cover a wide belt extending along the western central strip from the Arctic to the Gulf of Mexico. At the close of the Cretaceous there came a great series of earth-movements which culminated in the formation of the Rocky Mountains and the elevation of the deposits that had been accumulating in the Cordilleran geosyncline, which had been, with but a few breaks, below the sea ever since Cambrian times.

The Tertiary Period thus opened with an elevated continent, and during the whole period the waters of the ocean at no time covered more than a very small proportion of the continent and these areas of sea were mainly in comparatively narrow strips along the Atlantic and Pacific coasts and around the Gulf of Mexico. There were minor earth-movements, and in the Miocene, a great outpouring of lava by a series of volcanoes that stretched from Central America to Alaska, 200,000 square

the Indian earthquake of 1897 had a number of lines of great destructiveness ramifying over an area as large as England and extending across several tectonic* features, such as the alluvial plain of the Brahmaputra, the great boundary faults of the Himalaya, and probably even across the main axis of that folded region.

In 1886, a destructive earthquake occurred in the Charleston district of the United States, in a region that has no great structural features, either of folding or faulting, and which hitherto had been as quiescent as

SOME DISASTROUS EARTHQUAKES

Date	*Locality*	*Results*
1755	LISBON	Between 30,000 and 60,000 persons killed. Most of the city destroyed. Much loss of life and damage due to tidal wave produced by earthquake, centred at sea.
1857	NAPLES AREA	12,000 people killed.
1868	AFRICA, on west coast of SOUTH AMERICA	War-vessels carried two miles inland by wave due to submarine earthquake.
1891	MINO and OWARI, JAPAN ..	The two towns rased, 7,279 killed, 17,393 injured.
1897	SHILLONG, ASSAM	Great loss of life and damage to property.
1906	SAN FRANCISCO	700 persons killed, enormous damage to property. 200,000 rendered homeless.
1908	SICILY and the CALABRIA DISTRICT OF ITALY ..	76,000 persons killed, 95,000 persons injured. Most of Messina and many smaller towns and villages destroyed.
1915	CENTRAL ITALY	30,000 killed. 372 towns and villages destroyed.
1919	PORTO RICO	116 persons killed.
1920	NORTH AND CENTRAL ITALY	Many thousands killed. Enormous damage done.
1920	ORIZABA DISTRICT OF MEXICO	3,000 persons killed
1923	TOKIO AND YOKOHAMA, JAPAN	About half a million killed. Enormous damage, Tokio practically wrecked. Greatest earthquake in all human history.

the British Isles. This seems to suggest that not all earthquakes originate in a central focus of restricted dimensions connected with a fault or other tectonic feature visible in the surface rocks. Oldham argues that in such cases as those mentioned, and in others, too, the best explanation is that the origin must be more deep-seated in the earth and involves either a displacement of, or a change in volume of, the material in the layers underlying the outer crusts.

As already indicated, we can have no direct knowledge of the deeper levels of the crust, but chemical and physical considerations lead us to suppose that changes of mineral aggregation may take place in the magmas

* Tectonic features are those which belong to the structure of the earth's crust.

that there exist, and that these changes, which may occur almost explosively, may result in considerable changes in volume. Oldham then concludes: "It is not improbable that, in the material beneath the outer crust, changes . . . are taking place, some slow and gradual, others more rapid and sudden, but all accompanied by a greater or lesser change of bulk, either of increase or decrease; and if this be accepted, we find an explanation . . . of the forms and origins of earthquakes . . . the lesser earthquakes may be due to more rapid changes in smaller portions, the greater to transformations involving a larger bulk of material; whilst the greatest earthquakes, of first-class magnitude, result from similar changes involving a large bulk of material." Earthquakes are thus due, on this view, not to slow acting processes, but to a rapid development of strain.

Volcanic Activity

Earthquakes are one of the means by which Mother Earth relieves herself during her contraction, and as she ages, trying to accommodate a rigid skin to a shrinking interior; but there is still another way, that of volcanic activity, which may, or may not, accompany, or be accompanied by seismic activity. It is noteworthy, in the latter connection, that almost all the active, or recently extinct volcanoes of the world lie along two belts which are, approximately, coincident with those along which earthquakes occur. A short list of active volcanoes will illustrate the truth of that statement. Etna and Vesuvius, in Italy, and Stromboli, the island-volcano of the Mediterranean, lie on the Pyrenees—Alps—Himalaya line, whilst the greatest proportion of the active ones lie on what has been termed (as a result) the "girdle of fire", the line that encircles the Pacific Ocean; these include Sajiama, in Bolivia (the highest one in the world); Cotopaxi, in the Andes; Mount Elias, in the Rockies; Popocatepetl, in Mexico; Sangay, in Ecuador; Erebus and Terror, in the Antarctic; Tomboro, in Japan; Mauna Loa and Mauna Kea, in the Philippines.

Of recently active volcanoes, many also lie on that line, many of the mountains of the Andean and Rocky chains are recently extinct volcanoes, whilst those of New Zealand and Japan are well known, that of Fuji Yama being familiar to all from its appearance in so many Japanese pictures. A number of the islands of the Pacific Archipelago are volcanic in origin, and in some cases the central cone remains, while in others the cone does not reach to sea-level, but has been covered with coral and an island formed.

There are a few volcanoes that do not lie on either of the two main lines, for example, Hecla and Skaptar Jokul, in Iceland, and the little group in the West Indies, including Monte Pelée. In comparatively recent geological times, there were active volcanoes in Central France, in the Auvergne district, in the Hebrides, in Alaska, and along the line of the Great Rift Valley, in east Africa, e.g. Kilimanjaro.

Volcanoes have been called "the safety-valves" of the earth, and in a sense, that is what they are, for they are places where the earth's crust is broken through, more or less permanently, and where the potentially molten lava that exists at great depths, owing to the immense temperatures there, can find an exit, when it can and does expand. Were it not for such safety-valves it is possible that very disastrous explosive earth-movements would result.

It is noteworthy that the centres of volcanic activity seem to move nearer to the Equator as the earth gets older. Today there are the two lines of activity outlined above. In the Tertiary Period (some three to five million years ago) there was a belt of activity running through the Hebrides and Central France and Hungary; earlier still, in what geologists call the Permo-Carboniferous Period (see Geological Time Scale on p. 87)—just after the deposition of the Coal Measures, about 200 million years ago—there was a belt of activity passing through southern England (Devon and Cornwall) and north-central Europe, whilst earlier still, in the Devonian Period, there were volcanoes active in England and Scotland.

A volcanic district passes through stages. After the active period when lava is extruded from a vent, and a cone built up, there ensues a stage of occasional outbursts of steam and gas, with some solid matter, and then comes a stage when hot-springs and geysers are present. Such a stage is to be seen in the north island of New Zealand, where volcanoes were active until recent times. The hot springs of Bath represent a very late stage in the volcanic cycle which began in Britain far back in the Paleozoic Period. The Phlegrean Fields, or region of gas-emissions and hot-springs, near Naples, represent a mid-way stage in the dying-out process. There the famous Grotto del Cane is an example of gas-emission; the poisonous gas emitted from vents, in the floor of a small valley, lies on the ground, and although a man may walk through the valley and find no ill effects, since his head is above the level of the gas, a dog is suffocated by the carbon dioxide gas that, heavier than air, lies on the floor of the valley.

It has been mentioned, in passing, that an active volcano throws out solid matter; this may take the form of molten rocks (lava), or ash, or, if the outburst is explosive, of fragmentary material, or scoriæ. The last mentioned type of material is more likely to be extruded if the volcano has been inactive for some time, the crater partly solidified, and the "plug" thus formed, burst through with violence. A remarkable eruption of this type occurred in the West Indies in the year 1902, when Monte Pelée, which had been inactive for some time, suddenly became active. The "plug" of hardened lava that filled the vent was pushed up like a great cork, or spine, and for several days stood upright above the cone before it eventually fell to pieces.

The great eruption that destroyed practically the whole of the island of Krakatoa, in the Sunda Straits, in 1883, was the result of the explosion due to the sealing up of the vent of the great volcano that formed the island. So powerful was the explosion that it is said that the dust from it

was blown twice round the world, and helped to account for the wonderful sunset effects seen in Britain the following year. The sea was thrown into waves that inundated the coasts of islands several hundred miles away, washing small ships some distance inland. The effect of this tidal wave was felt as far off as the Australian coast.

Since the time of the Krakatoa eruption instruments have been devised for measuring the intensity of solar radiation above a station, and since this is affected by the amount of dust in the atmosphere it is possible to measure variations in the dust content of the atmosphere. Such measurements show some interesting results. In April 1932, seven volcanoes strung out along 200 miles of the frontier between Chile and Argentina became active. Explosions were heard 100 miles away and the eruption of much ash and dust put the surrounding districts in semi-darkness, a smoke column rose 30,000 feet, and dust fell for many hours in the city of Montevideo, 850 miles away. On the following day, May 7, an unusual amount of dust was recorded in the atmosphere at Wellington, New Zealand, a maximum was attained on May 26; there were also unusual skies seen in South Africa. But the solar-radiation station on Table Mountain, California, noted no dust effects.

The Alaskan volcano of Katmai burst into violent activity in June 1912, and various stations in the northern hemisphere recorded undue amounts of atmospheric dust, whereas no station in the southern hemisphere did so. It would therefore seem that volcanic dust, except in special cases—Krakatoa, which was very severe, and which lies practically on the Equator—is confined to the hemisphere where it is erupted. This is due to the atmospheric circulation described in Chapter X, especially the great upward movement of air over the equatorial regions and the consequent Pole-ward flow of air at high levels in the atmosphere.

There are volcanoes (unlike the erratic violent outbursts noted above) in which eruptions are continuous and almost non-explosive in character. These volcanoes often pour out vast quantities of lava, but do it so quietly that only the immediate neighbourhood is affected. The great volcanoes of Hawaii, Mauna Loa and Mauna Kea are examples of such; the lava is basic in character, and very fluid, pouring out gently and running down the slopes of the gently inclined cone, without much explosive action.

But even in the case of almost continuously active volcanoes there are times when the eruptions are more violent than usual, and then there are disastrous eruptions, such as occur in the case of Vesuvius and Etna, for example. In the case of the latter, there have been many violent eruptions on record, often accompanied with consequent loss of life, as, for example, in 1169, when the town of Catania was partly destroyed, and again in 1693, when there was great loss of life. The immense size of Etna has been referred to elsewhere, but it may be recalled that the cone is three times as high as that of Vesuvius, and covers an area of 500 square miles.

The emission and eruption of matter, whether as lava, or as ash or scoriæ, gradually result in the formation of a cone, or mound, around the

vent in the crust through which the lava comes. The cone is thus a result of the volcano's activity. Monte Nuovo, in the Bay of Naples, is well known to tourists; this small mountain is really a volcanic cone that was thrown up in an eruption in the year 1538. The conical shape that a volcano tends to have is affected by the nature of the lava emitted; if the lava is basic in character and very fluid, it will flow farther before being consolidated, and therefore the slopes will be gentle, for example, those in Hawaii; if the lava is acid, and, therefore, more viscuous, it will not flow so easily, or so far, and the slopes will be steeper, as in the case of the volcanoes of the Mediterranean region.

The symmetrical cone which naturally tends to result is marred in many cases by irregularities; these may be due to the existence of small vents and cones on the slopes of the larger one, or to eruptions which destroy part of an already existing cone, such as have occurred in the case of Vesuvius, where the present cone is situated inside the partial remains of an older and larger cone, which was broken by an eruption that formed the new cone.

Besides those eruptions which form cones and are localized, there have been, in the geological past, eruptions of lava of another type, called fissure-eruptions. In these, the lava issues fairly gently from an elongated fissure, and flows gently away, forming sheets of volcanic matter, such as those forming the basalt beds of Giant's Causeway, in northern Ireland, or the Deccan in India. In the Snake River plains of North America the basalts extruded in this way over an area of about 200,000 square miles and have a maximum thickness of 5,000 feet. The Deccan plateau basalts probably once covered double that area and are twice as thick at their maximum development on the west coast, near Bombay. In the Stormberg district of South Africa there are other basalts of this type. Eruptions of this trype have given rise to the largest known masses of igneous rock known on the crust. The lava is probably exuded in successive flows continuing over a long period.

Fissure eruptions often accompany that particular type of earth-movement that is known as block-faulting, that is, when portions of the earth's crust are moved in a vertical direction, relative to the surrounding crust. It is considered likely that part of the North Atlantic Ocean was formed by the foundering, or sinking, of a great tract of the crust, and that at the edges of this sunken mass, molten matter was forced out to form the volcanic rocks of the Hebrides and northern Ireland. The sinking of the crustal block would displace molten matter underneath it, consequently an eruption would follow. That eruption, or rather extrusion, took place along a line of events, or a system of vents, and was not, except for certain points, localized, in point, that is in what we usually call volcanoes.

Similar extrusions of lava from fissures have taken place in Iceland within historical times. In the summer of 1783, a fissure 20 miles in length, near Laki, poured out a great flood of basaltic lava which spread

over the country until 218 square miles had been covered with the fiery matter. As the eruptions slowly died down, the fissure became stopped up in places and a series of small cones was formed along the line of it, and these continued to erupt for some time afterwards.

The Source of Molten Volcanic Matter

Something may now be said about the source of the magmas that are poured out by volcanoes. It is not necessary to suppose, as was once done, that there are reservoirs of already molten material under every volcano, which under the influence of earth-movements are squeezed and so some of the material is exuded on to the surface. A later suggestion that was made when it was discovered that there are radioactive materials in the crust was that the heat engendered by such substances accumulated in the sub-crustal layers until it was sufficient to melt the rocks which were then extruded. Later work has shown that his explanation will not suffice, for it is now known that the basic layers of the lithosphere do not contain so high a proportion of radioactive matter as do the upper acid layers, and the outer shell is not so thick that its base is permanently molten.

There is still very much that is not known about the origin of the magmas, but the convection-current theory already mentioned is perhaps the best at the moment, that is, the suggestion that there are currents of heat within the earth which ascend in certain areas. It may be that this heat raises the temperature of the rocks to temperatures at which normally they would be fluid, but are actually only potentially so owing to the pressure of the superincumbent rocks. If for any reason that pressure is locally reduced then the rocks may become actually fluid and so be capable of extrusion on the surface as lavas. Some igneous rocks may actually have been formed in the place in which they are found, at comparatively shallow levels, in the crust by alteration of existing rocks by ascending gases of very high temperatures.

Yet another hypothesis for the origin of molten rock matter, or magmas, has been put forward by Dr. J. S. De Lury, in his Presidential Address to the Geological Section of the 1945 meeting of the Royal Society of Canada. He suggests that magmas may be formed at comparatively shallow levels in the crust by the fusion of material there by the frictional heat engendered as a consequence of crustal movements, which movements are due to thermal contraction. He does not consider that crustal magmas are the relics of a former molten state of the earth.

There is this to be said in support of the new view, that igneous rocks, and especially granites, often occupy the centre of great folded masses, forming the core of mountain chains. It would seem in the present state of knowledge that any hypothesis is purely tentative, and it may well be that no single one will satisfactorily account for all magmas. In this, as

n other geological problems, experimentation is impossible, so that theorizing is dependent on observational data and that is still being accumulated. But whatever our modern views may be of the origin of vulcanism, there can be little doubt that it was the experience of that activity, with the deduction that there was a place of perpetual fire beneath the earth's surface, that helped in no small measure to develop and foster the idea of a material Hell below the surface, an idea widely held during the Middle Ages.

Speed of Volcano-building

Something may well be said of the rate at which volcanoes build up their cones, although only two examples can be given from modern times, therefore no definite conclusions can be drawn. But since one of the examples was thoroughly observed throughout the formation of the volcano it is of considerable interest. Reference is made to the new Mexican volcano of El Paričutin, which lies 200 miles due west of Mexico City. In February 1943 many earthquake shocks were felt in the district, on the 19th of the month there were as many as 300. On the following day, an Indian farmer was ploughing one of his fields when to his terror he saw smoke spiralling upwards from the field. That night there was an explosion and eruptions continued thereafter. At the end of the first day of volcanic activity, there was a cone 100 feet high and within a week it had reached 550 feet, and by the end of the following September it was 1,500 feet high. The explosions followed one another in rapid succession during the early existence of the new volcano, and there was much expulsion of gas and a great deal of smoke.

Later there was much fragmentary material, largely composed of red-hot bombs which were often blown two to three thousand feet into the air. Two days after the first explosion, lava began to pour out from a crack in a neighbouring field about a quarter of a mile distant. This lava stream flowed for six weeks by which time it was a mile long and 100 feet thick. By early June 1943, eight lava-streams had issued from the cone itself and the crater was filled with lava to within 50 feet of the rim, and through the congealed blocky surface ashes were being erupted. Each lava flow was preceded by violent explosions, but there were few explosions whilst the lava was actually flowing. Several more lava-streams broke out of the cone during the following months. The lava was of an andesitic basaltic type similar to that from other extinct volcanoes in the neighbourhood, and thus came from the same magma.

There had been no previous volcanic activity in the district within human memory—although there were many extinct volcanoes—with one exception. This occurred in 1759, at Jorullo, 50 miles to the south-east, where a new volcano suddenly appeared in that year and which built a

cone 1,000 feet high during five months of activity. It will be noted that this is approximately the same rate of building as with El Parícutin, 1,500 feet in seven months. This correspondence may be only coincidental.

Summary

The continual readjustment that is always going on in the crust of the earth due to its being situated on a shrinking interior, and to other causes, produces forces and stresses which can only find relief in sudden movements and explusions of molten matter, and these tend, at any one period in geological time, to take place along certain belts, where there is crustal weakness. Occasionally, however, there are disturbances both seismic and volcanic in other regions, but these are not common and when they do occur they can nearly always be traced to the former existence of crustal weaknesses in the geological past.

We have already noted the fact that folding and faulting has occurred in various parts of the earth at various stages in its history. One illustration will suffice. On December 30, 1944, an earthquake shock was felt over much of northern England; it lasted for some two minutes. Little damage was recorded, one large chimney was cracked and had to be pulled down. It was, however, the strongest shock felt in the area since the North Sea earthquake of June 7, 1931. The seismograph in the Isle of Wight which recorded the shock gave its intensity as equal to that of a depth charge exploding five miles off the coast, or of a tank passing 100 yards distant. Determination of the focus of the earthquake showed that it originated in what is known as the Pendleton Fault, a fault which affects the Carboniferous and newer beds of the district and which was formed during the cycle of earth-movements that took place at the close of the Paleozoic Era.

CHAPTER VIII

THE EARTH'S EPIDERMIS

THERE is yet another solid layer of the earth to be noted, the outer skin, a discontinuous covering of the lithosphere that varies in thickness from about an inch to many feet. And yet, in many ways, this layer is the most important of all the layers of the crust. It is the soil—and in it grow the plants, whilst on and in it lives the fauna of the world. To strip the earth of its soil would be to starve all terrestrial organisms, including man. Grenville Cole has said, "The soil, considered as a rock, links common stones with the atmosphere, and the dead dust of the earth with the continuity of life."

Yet strangely enough, our scientific knowledge of the soil has been but very slight until recently. Soil science, or pedology, as it is called, is probably not even a name to most people. Man had naturally learned something empirically of the soil since he became a tiller of the land early in Neolithic times. He would have realized quite early on the value of ploughing (turning up the deeper parts to the action of the weathering agents), he would have soon realized the need for irrigation in dry areas (this was practised long ago in Egypt and Mesopotamia) and for drainage in water-logged tracts. And, too, at an early stage in the development of agriculture there must have come some knowledge of the fact that some crops did well on certain soils and not so well on others. English farmers learned, as long ago as Anglo-Saxon times, the value of crop-rotation and the need to let the land lie fallow at times; such knowledge is seen in the threefold division of the common manorial fields. But all such knowledge was empirical, it was achieved by trial and error, there was little inkling of the reasons that lay behind the procedures found useful.

When in the nineteenth century the first attempts to make a scientific study of the soil were essayed the approach was chemical and geological, that is, the soil was regarded as a purely inorganic and static material. It must be noted, however, that there was one man who realized the part that living organisms play, for Charles Darwin drew attention to the great part played by earthworms in soil-formation, by their digestive action, thus making it finer in texture. He estimated that in an acre of average garden soil there were about 53,000 earth-worms and that in every year about ten tons of soil passed through their bodies, with the result that they spread fresh, finely textured soil on the surface at an average rate of an inch every five years. Darwin showed that in this way worms were continually turning over the soil and that their burrows permitted more light and moisture to penetrate the soil.* Soils were chemically analysed.

* Recent work at the Connecticut Experimental Station has shown another way in which worms add to soil fertility. Worm-casts have been found to contain plant food elements in larger amounts and more easily-available form than the surrounding soil does, e.g. available phosphate seven times more, potash eleven times, nitrate five times and magnesium three times.

They were regarded as the residual matter left over after the disintegration of the surface rocks by weathering and thus bore a direct relation to the underlying strata.

We know now that that method of approach to the subject is fallacious. The same type of parent underlying rock can and does give rise to quite different types of soil if the climatic or other conditions alter. For, as a result of much work in Russia, America, Germany and Britain—these countries are listed in approximately the amount of work done in the respective countries—we know that the soil is a complex and dynamic organism, alive with innumerable bacteria and that its formation and development is affected by many factors. The source of the greater part of soil material is, in general, the underlying rock, although there are great tracts of the earth's surface where this is not the case. The soils of such tracts have been brought to their present position as a result of floods or glacial action. Much of the Northern Plain of Germany, large areas elsewhere in northern Europe and much of northern and eastern England, for example, are covered with glacial drift deposited there when the great ice sheets and glaciers of the Pleistocene Ice Age melted, and these deposits were carried from sources sometimes a considerable distance away.

Soil Profiles

The new method of study, which was developed especially in Russia, is to study a vertical section, or profile, as it is called. This is found to consist of several more or less well-defined layers, or horizons. Anyone who has dug a trench or hole in virgin soil knows that such stratification is encountered in the process, and that there is a gradation downwards from the turf and dark humus layer at the top to the solid unweathered rock at the base. Two of the greatest Russian scientists in this field of study are V. V. Dokuchiaev and K. D. Glinka whose text-book on the subject is a classic. These and other Russian pedologists have essayed a classification of the soils of the world, to which we return later in this chapter.

Because the pioneer work was done in Russia and the soils types there were given local names, the nomenclature is unfamiliar to us, but the same tendency to use the names of districts where things are first studied as names for those things was exhibited in the case of the stratified rocks of the lithosphere when the science of geology had its birth in Britain a century or more ago, with the result that many rocks far better developed elsewhere still bear the name of the place in Britain where they were first studied.

In general, there are in a typically English soil profile three main horizons. There is, at the top, the elluvial horizon which is in direct contact with, and therefore much influenced by, weather conditions; below, there is the illuvial horizon which receives and absorbs those

materials that are washed down into it, either in suspension or solution from the top layer; and there is, at the base, the parent rock, which to a great extent determines the nature of the soil above it.

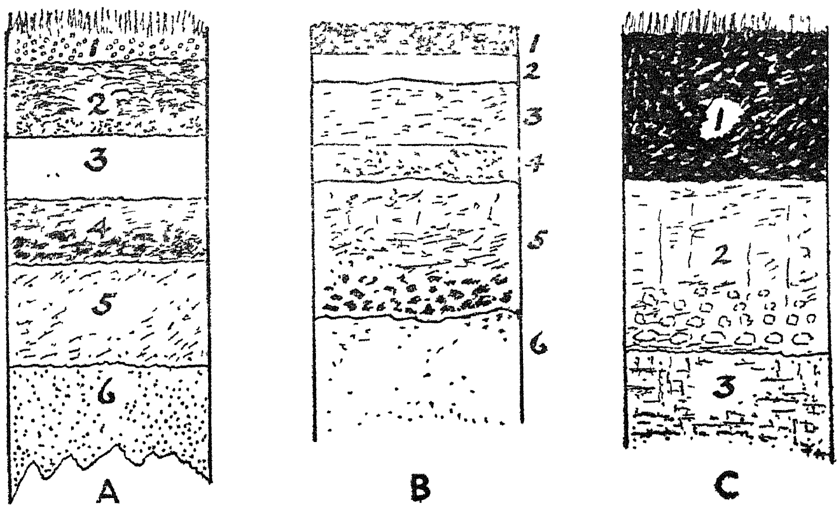

FIG. 18. TYPICAL SOIL PROFILES

PODZOL (A)

1. Leaf litter, with fine roots Forest above
2. Dark humic matter, passing down into sand.
3. Light-grey bleached sand—characteristic of this soil type—due to excess of rain over evaporation, therefore downward percolating water.
4. Dark brown sandy layer, often cemented by salts washed out of layer 3.
5. Rusty brown sand, passing down into
6. Parent rock—light brown loose sand.

Profiles similar to above common in Britain.

TUNDRA (B)

1. Thin greyish-brown organic layer, mainly humus.
2. Yellowish-grey, loose loam
3. Greyish-blue fluid layer, about 4 ins.
4. Brownish-yellow loam.
5. Compact brownish-grey horizon, with dark organic spots towards base.
6. Ever-frozen layer, about 30 ins. from surface.

CHERNOZEM (C)

1. Thick black soil, characteristic of this horizon. About 30 ins.
2. Calcareous layer, with lime concretions at base. About 2 feet.
3. Parent rock.

Some rocks are hard, some are softer, some are soluble in water, especially if, as in the case of rain water, it contains carbon dioxide in solution, so becoming a weak acid (limestone is an example of this type of rock), and therefore the soils on such rocks are usually very thin, since a greater part of the mineral matter has been dissolved out. Some rocks such as

clays are insoluble and impervious and so hold up the downward seeping water, and thus producing in low-lying areas a water-logged soil. All these varying factors affect the nature and composition of the soil, but greatest factor in determining soil type is climate. Especially is the amount of rainfall important, for much downward seeping water tends to dissolve mineral matter out from the upper layers and redeposit it in more concentrated form in lower levels of the profile.

Composition of Soils

What is the soil made of? There are four main constituents. There is, firstly, the mineral matter. The particles of this inorganic matter vary in size from that of pebbles (which have broken off from the parent rock and usually are most common at the base of the profile), to colloidal particles of 0·002 mm. diameter. A rough grading of the soil can be made by shaking up a little soil in water; it will be noted that the larger particles settled to the bottom of the vessel fairly quickly after quiesence, whilst there will be a muddy liquid above which gradually clears as time passes, the finer the particles the longer the time of clearing of the water. These very fine particles are clay, so that a rough idea of the amount of clay and sand can be obtained by such a test. The proportions of sand and clay in a soil make a great difference to the character of the soil. Clay absorbs and loses water very rapidly. It is this rapid loss of water by clay which causes such soils to crack in a dry period. Sandy soils are much more porous and are, in general, well drained.

The second constituent of the soil is the organic matter, or humus, of which gardeners are so prone to talk. It is this organic content that serves to differentiate soil from rock in the geological sense—rock is entirely inorganic. The nature of the humus varies with the type of micro-organisms that are present in the soil, and these in their turn vary with the amount of water that is more or less permanently present. In water-logged ground, whether caused by surface flooding (such as is the case with land near easily floodable rivers), or by a high water table (the level to which the soil and rocks are permanently saturated with water), the more valuable of these organisms die off. It is because of this that drainage of land is so important if the soil is to be in good condition for plant production. The degree to which the soil is aerated also effects the life of the organisms; there lies one value of ploughing and digging for such processes bring fresh soil into direct contact with the atmosphere. A healthy soil contains millions of such organisms which greatly assist in the rotting of manure and other vegetable matter, and so make their fertilizing contents readily available for the plants growing in the soil. If there is a complete absence of microbic life of this sort, any vegetable matter in the soil tends to turn, not into humus, but into peat. This is the

reason that peat occurs in bogs, i.e. in water-logged areas where bacterial life is at a minimum.

The third constituent of the soil is the soil-water. This is water which contains various salts in solution, of which the main constituents are nitrogen, potassium, lime and phosphorus. These materials are obtained by solution out of the parent rock or from the vegetable matter growing in the soil.

The fourth constituent is the soil-air. This contains a higher proportion of carbon dioxide than does the atmosphere, and it is saturated with water-vapour. It is clear that where the land is water-logged there can be no soil-air. As already stated, earthworms play a great part in aerating the soil, as do also the various processes of cultivation.

Recent research has shown that there is another important factor involved in the production of good soil, namely the presence of bacteria. Bacteria represent the smallest living things, the average bacterium is an organism of minute size, so small that a special unit of measurement is used in describing it. This unit is denoted by the Greek letter μ (pronounced "mu") and is one thousandth of a millimetre. A bacterium varies from six to ten μ in length and one μ in diameter. There are any number from two to four thousand million bacteria in every gram (about a salt-spoonful) of good soil, but even this number represents less than 1% of the said volume.

There are several types or groups of bacteria, feeding on different substances and performing different functions in the soil. One group feeds on cellulose in plant remains and so helps in the breakdown of cellular structure. Another group attacks substances of the phenol type (carbolic acid) and is very important in agriculture since animal urine contains such substances and these would accumulate to an extent when they become poisonous and inimical to plant growth were it not for the action of the bacteria which decomposes the phenolic matter. A third group, which occurs especially in the nodules on the roots of leguminous plants—peas, beans, clovers—fixes nitrogen, that is such bacteria convert atmospheric nitrogen into compounds which are essential for plant growth.

Bacteria thus act in two ways, they decompose vegetable and animal matter in the soil, so providing plant food, and they build up plant food by a synthetic process. Some soils are deficient in the type of bacteria needed to produce the food necessary for certain crops. It is now possible to prepare cultures containing those bacteria and so add them to the soil. For example, it was found that lucerne, which is a valuable fodder plant, did not grow well in the north and west of England and the fault was traced to an absence of suitable bacteria. After these organisms had been added to the soils of those districts, lucerne was grown satisfactorily. It is true to say that without the activity of these bacteria of various groups, there would be insufficient plant food produced to feed the population of the world.

Soils differ as a result of their origin and their mode of formation.

Variations in the parent rock will obviously produce variations in the superincumbent soils. Climate is, however, the greatest determining factor in soil-type. The situation has an influence, too, for whereas on steep slopes the soil cover to the rocks will be very thin or non-existent, in river valleys and on plains there may be many feet of good soil. Rain-wash accumulates to a considerable depth at the foot of slopes and consists largely of the soil washed down from above, and on slighter slopes there is often a general slow downward creeping of the whole soil mantle under the action of gravity, with the result that lower parts of a gentle slope bear thicker soil than higher ones do.

Soil Belts and Types

As alreay mentioned, much of the work done on the description and classification of soils has been carried out by Russian scientists, in this and the preceding century, although today many other countries are realizing the value and need for such work. The Russian pedologists were especially favoured because they lived in a country which formed a huge land-mass stretching from within the Artic Circle southwards to semi-tropical regions and which, except for the Ural Mountains, consists of a fairly uniform plain. Climatic variations would therefore be very marked and practically zonal, that is, dependent on latitude.

Dokuchiaev as long ago as 1879 suggested that climate was the main influence in determining the type of soil produced in a region, although minor variations in type might be caused by variations in the underlying rock, the presence of mountain-belts, the amount and nature of the vegetation and the time during which the soil had been allowed to accumulate without interruption or change of conditions. Russian pedologists distinguish several main soil types which can be traced across European and Asiatic Russia in great east-west belts of varying width, running more or less parallel to the lines of latitude and therefore to the climatic belts. In general, these types are typical of the soils of corresponding climatic zones in other parts of the world, but in no other area is there such a continuous land-mass for their zonal development; a short description of the main types is given below.

The most northerly belt is that of the Tundra soils, which stretches along the northern coast of Russia and Siberia, with an average width of 50 miles or over. Although the surface temperature of this area rises above freezing-point during the short summers of those high altitudes there is a permanently frozen horizon a few feet below the surface. This horizon causes difficulties in building construction, for the pressure caused by the erection of buildings often results in partial thawing of the soil in the frozen lâyer with the result that the building tends to subside slightly, and cracks develop. Above the frozen layer is a shallow soil which, in summer, is semi-fluid or water-logged, for water cannot percolate

downwards through the frozen layer. There is, usually, a surface horizon of humus and below that are a few inches thickness of greyish-blue soil. The vegetation, because of climatic reasons, is very limited and consists of mosses, lichens, small shrubs, and, in summer, many short-lived flowers. Similar soils occur in northern Canada.

To the south of the Tundra soils comes the belt of Podzol soils which forms a broad tract some 900 miles in width and which is characteristic of the cold temperate and moist cool temperate regions. The dominant feature of Podzol soils is the presence of a highly bleached horizon not far below the surface. This is caused by the downward percolating water dissolving out and carrying downwards the soluble iron compounds which are redeposited at lower levels in the soil in a concentrated form so forming a harder horizon at the lower levels. Such podzolized soil profiles also occur in the coastal regions of Australia and are well seen in England, especially in well-drained sandy tracts such as the Cheshire Plain and heath-lands of Surrey and Kent. Much of Great Britain is covered with a variant podzol type, namely the Brown Podzol soil.

South of the Podzol belt in Russia there comes the belt of "Black Soil", or Chernozem, the famous black earth of the great wheatlands of the Ukraine. Soils of this type stretch from the Balkans to Manchukuo and form the cereal-growing areas. A typical profile has very dark upper horizons due to the large amount of humus retained at those levels consequent on the low rainfall of the regions in which the type occurs. Low rainfall means less water to seep downwards through the soil-layers. This humus horizon has an average depth of 28 inches. The lower part of the profile is characterized by concretions of calcium carbonate which have been deposited from solution from the water which does percolate downwards. Similar Chernozem soils occur in Canada (the black soils of the prairie wheatland area) and form a tract running through the United States from North Dakota to Texas, also in the Sudan, parts of South America and Eastern Australia.

South of the Chernozem belt lies the Brown Soils of Russia, which resemble those of the former belt in some respects but are lighter in colour. They cover much of central Asiatic Russia and especially the region around the northern shores of the Caspian Sea. South again are the Grey Soils or Serozem type, which are formed under arid conditions and are light grey in the upper part with a browner horizon below, and below that again is another greyish layer, which owes its colour to the presence of much calcium carbonate in the form of streaks and patches.

The characteristic soils of the Tropics are the laterites which are red or yellow in colour due to the presence of large amounts of the oxides of iron and aluminium. They are often as thick as 40 feet. It was once thought that they were formed as a result of the abundant rain which percolated downwards and dissolved out or washed away the siliceous matter in the surface layers and so left a greater concentration of the

above-mentioned oxides, but more recent work, especially in Australia, suggests that laterites are formed by a podzolization process. An original soil fairly rich in iron and aluminium oxides was subjected to heavy rainfall, the water dissolved out these oxides and redeposited them at lower levels in a more concentrated form. The top soil thus became lighter and was gradually eroded away with the result that the oxide-rich one time lower level now forms the surface horizon.

Soil Deficiencies

The importance of a knowledge of the soil to the farmer cannot be over-emphasized, especially when high productivity is vital, and many farmers have chemical and bacteriological analyses made of the soils from their fields in order to determine what crops are best suited to their land and what treatment in the way of manuring, liming and drainage is needed. This scientific approach to farming must necessarily result in increased crops. In fact, this, together with the improvements made in plant species, has literally made it possible to make two blades grow where once only one grew.

Much more study of the relationship between soils and crops, especially in connection with deficiencies in the former and diseases in the latter, is still needed although a great deal has been accomplished. It had long been known that lack of nitrogenous matter in the soil retards the growth of practically all farm crops and makes the stems of cereals very thin and fragile with consequent liability to damage by wind or rain. Lack of potash causes yellow striping of the leaves of cereals and a lack of clover in pasture. The black discoloration of potatoes when cooked is also due to the same cause. Phosphate deficiency gives rise to stunted plants and a purplish coloration of leaves and stems. Deficiency of boron results in diverse and severe effects, including heart or crown-rot in sugar beet, cracking of the stems of celery, hollow stems in cauliflower, and brown heart in swedes. The leaf blotch of apple trees and an appearance of burning on the edges of the leaves may be due to magnesium deficiency. This also gives rise to diversity of leaf effects, including brilliant coloration before early defoliation. Calcium or lime deficiency may result in the dying off of the growing points of plants shoots. It has even been suggested that the prevalance of some human diseases in certain areas may be due to a deficiency of certain elements, notably iodine, in the soil of the areas, which in turn affects the mineral content of the plants eaten there.

Another way in which knowledge of the soil is useful in saving both time and money is in connection with proposed plans for reclaiming waste or unproductive land. An analysis of the soil would tell whether it would be worth cultivating, or what treatment would be needed to make it so. Especially is this important if particular crops are to be grown since different crops require different mineral foods in the soil. Here the

botanist and the pedologist have to work together. The importance of soil knowledge has been acknowledged by the State, for in 1939 the Board of Agriculture officially recognized the Soil Survey of England and Wales and appointed a Director. As long ago as 1907 some mapping of the soils had been carried out in Dorsetshire, but this and subsequent work in other places was on a geological basis. The work of the Soil Survey which is gradually producing a detailed map of the soils of this country is based on the new methods and outlook outlined above, and will prove of great value to the prosperity of British agriculture.

Soil-Erosion

The importance of the soil leads on to a consideration of what is one of the major tragedies of our time, namely soil-erosion. An exhausted soil, that is one from which the valuable plant-feeding substances have been removed by over-cropping, can have its fertility renewed by suitable treatment, but an eroded soil cannot be replaced. Yet all over the world there are great areas where, for various reasons, that all-important thin outer layer of the earth has been or is being lost with a consequent irreparable loss to food production. Bad methods of farming and deforestation are the main causes of this loss. Growing the same crop, e.g. wheat, year after year, in parts of the Canadian Plains, has used up humus which binds the soil together, with the result that the powdery soil left has been blown or washed away, thus making large tracts useless.

A writer in a farming journal recently observed that a journey through Arabia led him to the conclusion "that deserts are mostly man-made". This view is borne out by another quotation from *The Rape of the Earth*:

> "Today, destruction of the earth's thin living cover is proceeding at a rate and on a scale unparalleled in history, and when that thin cover—the soil—is gone, the fertile regions where it formerly lay will be uninhabitable deserts. Already, indeed, probably nearly a million square miles of new desert have even formed, a far larger area is approaching desert conditions, and throughout the New World erosion is taking its relentless toll of soil fertility with incredible and ever-increasing speed."

It is estimated that 200 years ago there was a blanket of fertile soil, nine inches thick, covering an infertile subsoil, in the United States. Today, that blanket has been reduced to an average thickness of six inches, and not only is it thinner, but it contains less available chemicals, less moisture and less organic matter for plant sustenance. Some areas have been completely eroded of their top soil. The causes of this loss in quantity and quality of soil are varied—there is bad farming, but above all there is deforestation. The urge to grow big crops of the same cereal

year after year on the same land, once very fertile when it was first ploughed from the virgin prairie soils in last century; ploughing up and down slopes, with the result that surface drainage could carry away the top-soil more easily; clearing away of the woodlands that were once so widespread, all these things and others helped to convert great areas of the United States into a wilderness.

A tract of country, some 500 miles wide, and lying at an altitude of 5–6,000 feet up in the eastern foothills of the Rockies, and stretching northward from northern Texas to the Canadian border, is known as the "Dust Bowl". There, the soil had been so impoverished that winds were able to remove the dusty layers that remained after the humus and other valuable constituents had been removed, and the settlers literally saw their fields blown away. Many of the farmers and their workers set off to seek for new land; between the years 1935–1939, 350,000 such men together with their families migrated into California alone. John Steinbeck has described vividly in his novel, *The Grapes of Wrath*, the experiences of a family driven from its home on the Plains by soil-erosion.

So serious had the position become that the Federal Government inaugurated, some 10 years ago, a Soil Conservation Service. This Service has already produced good results, for it has developed and taught fresh methods of cultivation to allay the evil. Some of the methods suggested are contour-ploughing (i.e. ploughing parallel to the contours, round the hill not up and down), and the planting of deep-rooted, water-holding plants, such as clover, on steep hillsides. Up to 20% higher crop yields have resulted from an application of these methods in some cases.

Deforestation acts in two ways in accelerating soil-erosion. The cutting-down of great tracts of woodland results in a decline in the annual rainfall, so that if the area were previously one with a low rainfall it might well be that the new figure falls below that necessary for the production of plant life in sufficient amount to produce humus to bind the soil, and the soil dries out rapidly and so becomes liable to wind-erosion. Many areas of the world have been turned into desert through drastic deforestation, for example, the northern shores of Africa, and parts of Central France. The rainfall in England is today much less than it was in Roman times, when most of the country was covered with forests. This fact is shown by the lower water-table (level of saturation of the rocks) and the drying-up of springs that once supplied the hill-camps and settlements whose remains are so numerous in some parts of the country.

But drastic removal of the trees also allows the agents of denudation to attack the earth's surface more rapidly and effectively. Dense vegetation breaks the force of heavy rain, for example. Loss of soil through deforestation can be seen in parts of north-western China, where the floods of the Yellow River have removed the top layer from large tracts.

The same thing happened in the past, in the time of the Sumerian City States, when the cutting-down of the great Elamite forests resulted

in the washing away of the top-soil by the overflowing flood water of the Tigris. This soil was carried down by the water to lower levels and formed dams which impounded the flood water and caused disastrous inundations of settled areas.

A proof of the effect of woodlands in preserving soil is afforded by the United States government, which is planting a wide belt of trees along the flanks of the Rockies to help in soil-conservation. In this matter of soil-conservation, prevention is certainly better than cure.

Nor must it be thought that our own country is exempt from the evil of soil loss; even though it be on a smaller scale than in other countries it can nevertheless be serious. Wind-erosion acts especially in areas where the land is flat and there are no wind-breaks, such as Lincolnshire and the Fens, and particularly where the soil is light and sandy. On some of the hill-farms of Kent and Sussex, if there has been up and down ploughing, instances have been noted of serious loss of soil from the upper parts of the fields, the winter rains carrying down the soil to lower levels.

Gully-erosion is also fairly common in some places. This is where heavy storms cause downward rush of water along natural or cultivation-produced channels which become widened and so the soil is removed from wide strips. Bad ploughing is again primarily responsible. Dr. S. Graham Brade-Birks quotes an instance, in his book, *Good Soil*, of a case in Lincolnshire, where after a thunderstorm, in 1939, a field of winter wheat on Chalk was gullied to a depth of a foot, and a great mass of washed flints was spread out at the foot of the gully. From the same book the two following quotations are obtained, relevant to soil-erosion—the first runs:

> The dust is gold that bears the harvest;
> Save the soil that grows our bread;
> Let not wind and rain remove it,
> Guard with care for years ahead.

And the second, which originally came from the Tennessee Valley Authority, is:

> Hordes of gullies now remind us
> We should build our land to stay,
> And, departing, leave behind us
> Fields that have not washed away;
> When our boys assume the mortgage
> On the land that's had our toil,
> They'll not have to ask the question
> "Here's the farm, but
> Where's the Soil?"

CHAPTER IX

SEAS AND OCEANS—THE HYDROSPHERE

THE fact that the word "earth" is used for both the world as a whole and for that part of it more correctly termed soil, rather tends to make us think of our globe as entirely solid matter. Such is not the case, for there are two layers, one aqueous, the other gaseous, which surround the solid shells of which we have written in the foregoing pages. A casual glance at a global map or a globe itself will show that so far as the actual surface is concerned the waters of the world are very prominent features. Could we but observe the earth from, let us say, the moon with a sufficiently powerful telescope we should realize that Mother Earth's face is more watery than solid.

The total surface area of the earth is about 197 million square miles, and there are about 140 million square miles of water—seas and oceans—i.e. 72% of the total area. Some of the seas are very shallow and are really flooded portions of the continental shelves, or submerged outer borders of the continents, e.g. the Mediterranean, Baltic, North and Irish Seas. The last two were land in comparatively recent geological times. If allowance is made for the continental-shelf seas, the total area of the continents is some 64 million square miles, whilst there are about 130 million square miles of surface where the ocean waters are one thousand or more fathoms deep, that is, twice as much area of ocean deeps as of dry land today. This proportion has, of course, varied to some extent in earlier geological periods, but on the whole it seems likely that the variations have not been very large. Most authorities believe, as we shall see later, that the ocean basins are fairly permanent.

The Ocean Floor

If the waters of the oceans of the world could be removed the surface that would be revealed would not be as flat as some suppose it to be, in fact the ocean floors are as diversified with hill and valley as is the surface of the earth, with perhaps even greater differences in level. This is what might be expected when it is recalled how much crumpling the crust of the earth has undergone. There are great mountain ranges below the waters, the tops of which rise above the surface as oceanic islands. One such mountainous ridge runs north–south down the centre of the Atlantic dividing that ocean into two troughs. The Azores, St. Helena and Ascension Island are island peaks of that ridge. The Maldives and the Chagos Archipelago are the tops of another ridge that runs north–south in the Indian Ocean, whilst Hawaii is highest part of an east-west ridge

in the Central Pacific. Another Pacific mountain-ridge runs north–south and its summits breaks the surface to form the islands of the Marshalls, Gilbert, Ellice, Fiji and Tonga Groups.

These submarine mountains would form very striking scenic features were they uncovered, for in most cases, their slopes rise steeply from an ocean floor that may be 20,000 feet below the surface. So steep are some of the slopes in the oceans, especially those near some of the continents, that material on them would slide down under the influence of gravity, especially during earthquakes.

There are also depressions in the general level of the ocean floors—the maximum depth yet recorded is about 34,000 feet. It is an interesting fact, and of particular importance to geological theorizing, that the greatest deeps all lie in narrow belts comparatively close to land-masses. There is such a trough running parallel to the chain of the Aleutian Islands, and another farther south parallel to the island festoon of Japan and the Philippines. There is a trough off the coast of Brazil and another east of the West Indies. Others occur in the Central Pacific, alongside the ridge on which stand Fiji and the Tonga Islands, and to the south of Java. In many of these instances, the neighbouring land-masses consist of fold-mountains, and this seems to suggest that the deeps may be connected with the buckling of the crust that produces the mountains.

The under-water topography would not be so rugged as that of the land surfaces, as the only erosive agency is that of water in motion, and although bottom-currents may scour out channels, the resultant shapes would be more rounded than those of the land. Again, it has to be remembered that there is always a certain amount of deposition going on over most of the ocean floor and that, too, would tend to even out the irregularities of the floor.

It may be well here to remind readers that, usually, the continents do not immediately slope off into deep water from their coastlines. There is, usually, a shelf of variable width, on which the water is fairly shallow, before the edges of the sial blocks, which are the continents, fall off steeply to the oceans deeps. Many islands, e.g. the British Isles, are really portions of the continental shelf that rise above sea-level. Other examples of such shelf-islands are those of Japan on the continental shelf of eastern Asia, and Newfoundland on the North American shelf.

Another feature of the ocean-floor which has only recently been discovered is the existence of deep canyons on the edge of the continental shelves. The best known example to date is the Hudson Canyon off the shore of New Jersey in North America. These canyons may be up to 60 miles in length, 4 to 8 miles wide and the central deep may lie 4,000 feet below the surfaces on either side. Such remarkable canyons —their average side slope is about 1 in 30—have been noted elsewhere on the eastern shelf of North America and off California.

The discovery of these canyons is mainly due to the work of Dr. Vening Meinesez, of the Netherlands Geodetic Survey. He has surveyed

large tracts of the Pacific and Atlantic Oceans with an echo-sounding apparatus. This is a development of the mechanism used in the War of 1914–1918 for detecting submarines, and works on the principle that sound or electrical waves emitted from a transmitter are reflected back from solid objects. The time of reception of the reflected rays—recorded by suitable apparatus—compared with the time of transmission (the speed of the waves being known), will give the distance of the reflecting object. Ships use echo-sounding devices for sounding and continuous records can be made along the course sailed over. In this way, traverses of the ocean floors can be made and their contours can be mapped just as the contours of the land surfaces are mapped.

Oceanographers and geologists are not yet agreed on the origin of these canyons. It has been tentatively suggested that they may be formed by erosion of the sea bottom by basal currents heavily laden with silt and which, therefore, have considerable eroding power. Such currents would not easily mix with the surrounding water. But some authorities do not consider this theory entirely satisfactory. In fact, at the moment, our knowledge of the ocean floor is still in its infancy.

The Ocean Waters

After all, oceanography, as the science of the ocean is termed, is a comparatively young science. It may be said to have begun when, in 1872, the British Government sent out H.M.S. *Challenger* on its three and a half years voyage of research. The scientists on board investigated many features of the ocean, currents, depths, deposits and salinity. As a result of their analysis of many hundreds of samples of water taken from many seas and oceans at varying depths, a good knowledge of the dissolved salts was obtained. The ocean water is salt, i.e. it contains dissolved mineral substances, brought into it by the rivers of the world as they erode the land. The *Challenger* scientist found that the waters of the open ocean contain in weight about 3·44 parts per cent of dissolved mineral matter, consisting of

Sodium chloride	77·7%
Magnesium chloride	10·8%
Magnesium sulphate	4·7%
Calcium sulphate	3·6%
Potassium sulphate	2·5%

and small amounts of magnesium bromide and calcium carbonate. The small amount of calcium carbonate is surprising at first sight, since it is so easily soluble in slightly acidulated water, such as rain, but it must be remembered that the great majority of living organisms in the seas secrete

skeletons or shells of calcium carbonate and this they must extract from the ocean water. The salinity of the water varies from place to place, depending on the amount of evaporation and the quantity of fresh water brought in. In seas where there is rapid evaporation and little fresh water added, the amount of dissolved salts will be higher than the average, such are, for example, the northern part of the Red Sea, where the salinity is 4·1 parts per cent, and the eastern Mediterranean where it is 3·9%. On the other hand, in the Baltic Sea, where there is little evaporation and a great amount of fresh water added by rivers, the salinity is as low as 0·2 to 0·8%. These differences in salinity, and consequently in density, produce currents, the lighter less saline waters tending to flow as a surface current towards the more saline regions; for example, a current flows in from the Atlantic through the Straits of Gibraltar, whilst another surface current flows from the Indian Ocean into the Red Sea. There are basal currents in the opposite directions.

The Movements of the Ocean Waters

Movement is a characteristic of the waters of the oceans. We are reminded by many a poet of the restless sea. There are three main types of movement—waves, currents and tides. Each of these is the result of different causes.

Air moving rapidly over water drags the surface water along with it, and this results in the piling up of the water to form waves. These wind-formed waves are of a very superficial nature in relation to the oceans as a whole and do not affect the deeper parts, although at the surface they may be very marked. A storm off the coast of India, in 1864, piled up water to a depth of 24 feet at Calcutta and drowned 48,000 people. In the open ocean waves may reach a height of 50 to 80 feet. The hurling of water up a cliff to a considerable height does not mean that the actual wave is that height, such water is thrown up as a result of the momentum of the water in the waves whose progress is stopped by the cliff.

Ocean currents are formed as a result of the differences in temperature of the surface waters of the globe. Water in the equatorial region becomes heated and tends to flow away to north and south, but the rotation of the earth imparts a deflection to the right which results in a clockwise direction of movement in the northern hemisphere and an anti-clockwise one in the southern hemisphere. This simple movement is, however, complicated by the fact that the face of the earth is not all water. Land masses deflect and break up the ideal circulation; for example, a current flowing westwards in the south Atlantic Ocean meets the bulge of Brazil and is split, part flowing up the coast and part down; this water is warm and therefore the east coast of South America is warmer than the west coast in the

same latitudes. Warm currents raise the temperature of the air above them and so tend to ameliorate the climate of the lands adjacent to them.

The best-known illustration of this sort of thing is the Atlantic Drift.

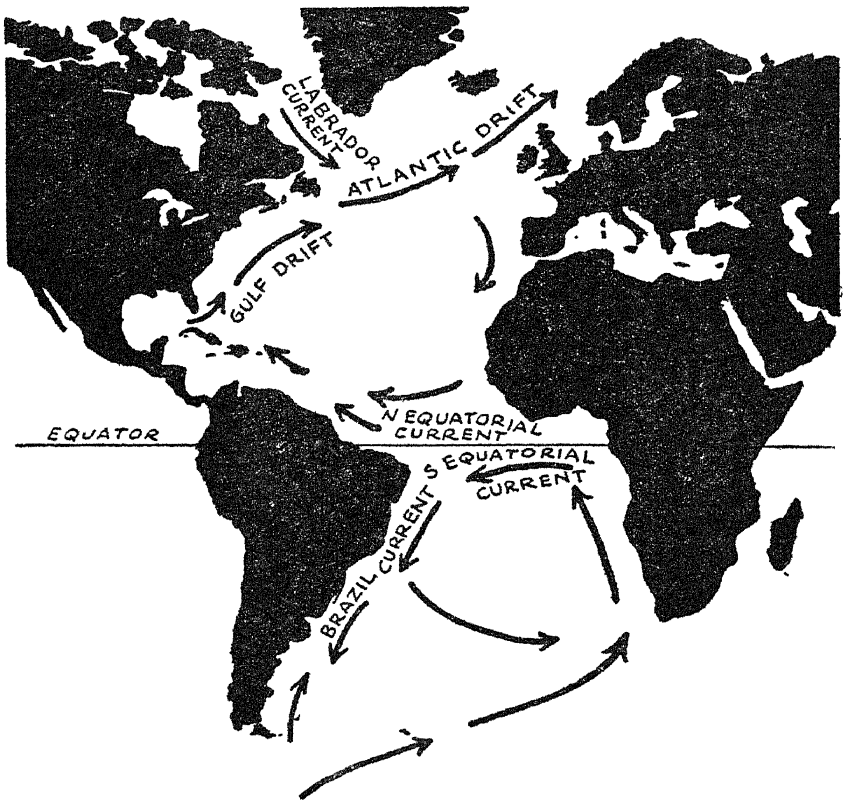

FIG. 19 CURRENTS OF THE ATLANTIC

The above diagram is a simplification of the actual currents, but the principal movements are indicated. Note the clockwise rotation in the North Atlantic and anti-clockwise in the South Atlantic.

This is really a combination of two currents—one of these is the Gulf Stream proper, a warm current flowing out of the Gulf of Mexico up the eastern coasts of North America, and off Newfoundland it meets the cold Labrador Current which is flowing down from the Arctic. This results in much foggy and misty weather. The combined currents, still warm, turn clockwise and flow across the North Atlantic as the Atlantic Drift and so reach the British area. The winds above them are warmed, too,

The effect of the Atlantic Drift in ameliorating the climate of Britain is not, however, so great as was formerly imagined. The prevailing south-west winds, blowing from a warm air-mass (see Chapter X), probably have far more effect in making the British climate mild for the latitude. Similarly, a cold current can worsen a climate, for example, there is a cold current, the Peru Current, flowing northwards up the western shores of South America, from the Antarctic, and this results in colder conditions on that side of the continent from those in comparable latitudes on the eastern side.

The third type of water-motion is a familiar phenomenon, it is the twice daily wave of water that moves around the earth from west to east as a consequence of the gravitational pull of the sun and moon, and is known as the tide. The sun and moon both exert a gravitational attraction on the earth and its surfaced waters, and since the latter are free to move they tend to pile up in the direction along which the attractive forces act, but since the earth is rotating, that piling-up effect is seen as a wave that moves around the earth. The highest tides occur at the times of new and full moon, for then the gravitational pull of both sun and moon are in the same straight line and so the attractive forces are pulling together, whereas at times intermediate (that is when the moon is waxing or waning), the two forces are acting at varying angles to one another, and their resultant is less than at the times of maximum attraction.

The tidal wave sweeps in towards the British Isles from the south-west, twice a day, but owing to the deflection caused by the land-masses in its path, this general direction becomes masked in various parts of the coast, for example, the tide is deflected by the islands of Islay, Kintyre and Arran, so that it flows almost in a direction from north of west along the northern coast of Ireland. The land-masses also affect the times at which the tide reaches various parts of the coast of Britain, for example, the main tidal wave coming in from the Atlantic is split by Ireland and again by south-west England. It takes that portion of the tide that flows up the English Channel as long to reach the mouth of the Thames as it takes that which flows up the Irish Sea to reach the North Channel, or that which flows around northern Scotland to reach the Moray Firth. This last takes an equal time to flow on down the eastern coasts to the Thames Estuary. This accounts for the more than average high tide in the latter area, for the tide that flowed up the English Channel in a morning would meet that which had flowed around Scotland on the previous evening.

Other local peculiarities of the tides are also due to the presence of land-masses, for example there are two false tides a day in Southampton Water in addition to the two normal flows. The main wave flows up Spithead and so reaches Southampton Water at, let us say, 12 a.m.; two hours later there is another wave at Southampton, it is the backwash of the wave that went on up the Channel coming up the Solent. Then just after 12 p.m. there will come the normal tide again and two hours later the second backwash tide of the day. This filling up of Southampton Water means

that there is insufficient time for the tidal waters to fully flow out again, so there is always highest water there—it is this fact that makes the port the main calling station for the biggest ocean-going liners.

Certain other peculiarities of the tidal wave are worth mentioning. If the wave—especially at high tide—enters an estuary which narrows rapidly and whose bottom shelves or shallows fairly quickly, there is a tendency for the waters to be piled up into a marked wall or broken wave which rises, several feet at times, above the level of the river water into which it is flowing. Such a heightened wave is called a "bore", and that seen on the Severn is a good example. The height of the bore—or of the tide for that matter—is partly determined by the direction of the wind at the time, a following wind enhances the effect, whilst an opposing wind will reduce it. A similar wave seen at times on the Trent is known as the Egar. Both on the Severn and the Trent this "bore" averages three to four feet under favourable conditions; on the Yangtze-Kiang river, in China, it may be as much as 12 feet in height.

Although we have talked—and rightly—about the tidal wave, it is the raising of the water-level every 12 hours around the coasts that is of importance from the economic point of view, for that decides the value or otherwise of a port. In the open ocean, the tidal undulation may only cause a raising of the level of about two feet, but when the tides reach the continental shelves, especially where these are close below the water-level, then there is a piling up of the tidal water and a consequent greater rise and fall; at Sharpness, for example, at the mouth of the Severn, there may be a rise in water-level of 30 feet at high tides. Other places show even higher figures, a range* of 100 feet occurring in the Bay of Fundy. Owing to the fact that the moon is revolving around the earth and therefore changes its relative position with regard to the earth and the sun, there is not a regular interval of exactly 12 hours between successive tides, but an interval of approximately 12 hours and 25 minutes, although high tides occur at the same time in the same place.

There is another movement of the ocean waters that deserves mention here, for although it is rather rare it produces effects that are spectacular and often disastrous. Reference is made to a tunami or seismic sea-wave, which is caused by a sudden rising or falling of a portion of the ocean floor during an earthquake. This displacement gives rise to a movement of the water which in its turn produces a surface wave of a rather peculiar character. The outstanding feature of a tunami is its great wave-length, which in the Pacific may be anything up to 900 miles. This means that the wave will be scarcely perceptible on the open ocean but when it reaches the coast it will be very marked, often reaching a height of a 100 feet. On account of their great wave-length tunamis travel great distances since the wave energy does not fall away so rapidly as does that of normal waves. The speed at which these waves travel varies with the ocean depth, in the case of the deeper Pacific Ocean the wave travels

* The tidal range is the difference in level between high and low water.

at the high speed of 450 miles per hour, whereas in the shallower Atlantic Ocean the speed may be only about 200 miles per hour.

A disastrous tunami affected large areas of the North Pacific in April 2 of last year (1946). It rose to a height of 100 feet at Unimak in the Aleutians, whilst over 2,000 miles away in Hawaii it devastated the town of Hilo in a succession of three waves each about six feet high and which travelled at a high speed. There was considerable loss of life—probably about 150—and much damage to property. The epicentre of the earthquake that caused the wave was situated in the neighbourhood of Unimak and the main shock was followed by several smaller ones during the following day.

The Effects of Ocean Currents

These continual movements of the ocean waters have an erosive action on the coasts of land masses and thus wear away the land to an extent that depends on several factors, notably the hardness of the rocks. A good illustration of this is afforded by the south-western coast of Ireland, where the harder old Red Sandstone ridges, alternating with softer carboniferous rocks, are more resistant and therefore form a series of prominent headlands, whilst the softer rocks between have been worn into deep gulfs. But in general, long continued action of the sea tends to form a gently curving coast, so that a highly indented coastline is usually a sign of that coast being geologically young.

In addition to erosive activity there is deposition, too, for often the currents and tides sweep material along a coast, especially if they strike it at a low angle. One famous illustration of this is Chesil Beach, that great stretch of pebbles that runs from near Lyme Regis to Portland and which has been formed by the movements of the sea-water as it rolls in from the west. Sometimes the tides, as they sweep more or less parallel to it down a coast, will carry sand and silt across a river-mouth and so form a bar. In the case of certain East Anglian rivers that has been carried so far as to prevent the river from flowing straight out to sea, and so lead it to make a sudden bend and run parallel to the coast for many miles before reaching open sea-water.

The Origin of the Oceans

The origin of the great ocean basins is still a matter of debate. The old idea that they were just the deeper wrinkles and hollows of the crust as it crumpled when cooling and contracting is rather too simple, for that would seem to suggest that the rocks under the ocean were more or less similar to those exposed in the continental masses. But recent gravimetric work has shown that the ocean floors are composed—at least so

far as the real deeps are concerned—of basaltic material, i.e. of "sima" and not of the continental "sial". Over vast tracts of the ocean floor the granitic covering is very thin. In other words, it does rather look as though the continental masses are in the nature of "islands", not only so far as the waters of the ocean are concerned but so far as the rocks that form their floors are concerned, too.

Many authorities believe that the great ocean deeps are probably unchanging and have persisted throughout geological time more or less in their present size and form. This idea may, however, have to be modified in the light of Wegener's Theory, for if the sial blocks which form the continents have drifted or moved over the earth's surface, there must have been a variation in the shape and position of the ocean deeps.

If we believe that the ocean deeps are more or less persistent then it follows that any deposits laid down in them do not reappear as rocks. This means that deposits that subsequently are raised above sea-level as new rocks can only have been laid down, either on the continental shelves or fairly close to land. This does seem to be the case, judging from the structure of the continents. Most of these consist of a central core of ancient rocks—the shields—around the edges of which are found rocks of varying geological age. Again, the type of deposit that accumulates very slowly in deep water is not often met with in consolidated form in the geological series. The great majority of sedimentary rocks show evidence, both from their structure, composition and fossil content, of having been laid down in fairly shallow waters.

The Deposits on the Ocean Floors

There was no knowledge of the deposits in the ocean deeps until the first cable-laying began about a century ago, since then information has slowly come in, and now there is apparatus capable of obtaining samples of the deposits many thousands of fathoms below the ocean surface. In the shallower parts of the oceans, that is down to about 2,000 fathoms, the main deposit is a calcareous ooze, made up of the minute tests or shells of simple living forms The solvent power of water increases with depth, so below this level calcareous matter is dissolved and in the floors that lie deeper, the oozes that form are mainly siliceous in nature, that is they are formed of the remains of minute marine organism which secreted a siliceous test or shell. Deeper still even those remains are absent and the deposit found there is a red clay, which is composed of the insoluble residues of such material as volcanic dust, wind-blown dust, meteoric dust and the debris from melting ice-bergs. This collects very slowly indeed as is shown by the fact that specimens that have been dredged up have been found to contain the insoluble teeth of sharks that have been extinct for long ages.

Only in few places, and these are all situated on the edges of fold-mountains where there has been much earth-movement and buckling, have any abyssal deposits been found as rocks in the stratigraphic series. Instances of red clay of Jurassic and Cretaceous age occur in the Dutch East Indies and in Barbados. It was once thought that the Chalk was of abyssal origin as it consists largely of the remains of *Globigerina*, which is one of the minute forms whose remains form the calcareous oozes, but it is now known that the types found in the Chalk are of shallow water type, and the rock also contains numerous fossils of types that inhabited shallow continental seas. Although in general it looks as though the deepest deposits rarely appear in the sedimentary rocks of the outer crust, it is possible, as the instances quoted above show, for movements to take place on such a scale that an area may be raised to form dry land and yet subside sufficiently beneath the ocean waters to become part of the great deeps.

The Geological History of the Oceans

There is a difference of opinion as to whether the oceans are permanent features of the earth's surface. Some hold that, in general, they are permanent. This idea is partly a survival from a pre-scientific age which regarded the earth as a static body, created as it now appears, and partly a consequence of the doctrine of isostasy which holds that the earth's crust is in equilibrium and that although the sial blocks may be contorted and affected by earth-movements, the sial is not so affected, and since the floors of the ocean are deemed to consist mainly of sial, they are permanent. But there are reasons for supposing that such is not the case. Gravity measurements have shown that the material below the ocean floors is not uniform in density, nor can we assume that the whole surface of the earth is in isostatic equilibrium—such may the state to which the crust tends, but it is doubtful if it has reached it. Again, we know from an observation of actual faults, whose throw* has been measured, that movements on a vast scale can occur, for example the Worcester Fault, in Cape Colony, has a downthrow of 12,000 feet. Others of comparable magnitude are known elsewhere in the world. A consideration of the foregoing leads us to suppose that it is possible for movements to take place of sufficient magnitude to form or eradicate ocean deeps.

The geological history of the oceans, as deduced from the structure of their shores and islands, bears out this view, that the oceans are not so permanent, at any rate in their present form, as was once supposed. A short outline of the history of some of the oceans is given to illustrate this.

Let us start with the Atlantic Ocean. It has already been noted

* The throw of a fault is the vertical distance that the beds on either side of the fault plane have moved relatively to each other.

(Chapter V) that a great land-mass occupied what is now the North Atlantic all through Paleozoic and Mesozoic times. There was a sea stretching east–west across the central Atlantic region throughout most of the same times, and its width varied from time to time; in the Lower Mesozoic it was narrow, but became much wider in the Cretaceous Period. To the south lay the continental mass of Gondwanaland, which persisted throughout most of the Paleozoic and Mesozoic Eras. Its persistence, in part at least, until middle Tertiary times is shown by the fact that similar shallow-water marine faunas occur in the pre-Miocene rocks of the Mediterranean area and the West Indies, this implies a coast line along which the organisms could spread. There is a difference in the fossil mollusca from similar beds of the Antilles and Northern Brazil, on the one hand, and the South Atlantic region, on the other, and this indicates deep water between the two regions—the westwards extension of the greater Tethys, as the trans-Atlantic sea is called.

Fossil evidence also suggests that Brazil and South Africa were also connected by land until the middle Tertiary. Gradually, however, faulting and tension increased (perhaps due to the westwards drift of the Americas) and the gulfs which had run north and south from Tethys became widened and extended, so forming an ocean somewhat similar to the present Atlantic, which consists of two basins separated by a narrower belt. The last land connection between the Old and New Worlds persisted until Paleolithic times (that is, at the beginning of the present era)—the Faroes and Iceland are fragments of it. About the same time, the Falkland Islands were separated off from the mainland of South America.

The Atlantic Ocean, therefore, came into being, through the gradual enlargement—as a result of successive subsidences of the crust—of great gulfs that projected north and south from Tethys. The Atlantic trough is thus a great sunkland, and not a fold valley. The main subsidence began in the Upper Cretaceous and was completed after the Miocene Period, and it is, therefore, contemporaneous with the folding that produced the Alpine-Himalayan Chains. The Andean and Rocky Mountain chains of fold-mountains belong to the same period, and were probably formed as a result of the crumpling consequent on the westward drift of the Americas. This westward drift would not only cause the folding on the advancing edge of the continent, but would also leave a belt of the crust on the east of the continent under tension and this would gradually collapse to form the Atlantic trough. The drift away from Africa would also tend to set up tension in the rocks of that continent, and about the same time there came the formation of the Great Rift Valley that runs from Palestine through the Red Sea and southwards through East Africa, and in which lie the great African lakes.

This great rift is somewhat akin to the Atlantic trough, but is more regular in its shape, owing to its much smaller size. The subsidences which formed the Atlantic were accompanied by great volcanic outbursts,

for example, the basaltic lavas of Eocene age which now form part of northern Ireland and the Hebrides, and the volcanic islands off the eastern coast of tropical America.

The Indian Ocean came into existence at the same time as did the Atlantic and in the same way, by subsidence, probably as a result of tension set up in the crust consequent on the eastward drift of Australia away from Africa. In the Atlantic, the subsidence was sufficient to cut through the westward extension of the Pyrenees and Atlas folds (which were continued into the Northern Antilles and Venezuela respectively), but in the case of the Indian Ocean the northern end of the subsidence was cut off by the Himalayan fold-mountains, probably because at the time of foundering of the Indian region, the rocks of the Himalayas were already undergoing compression and uplift.

The case of the Pacific Ocean is even more interesting because it has always been considered, by reason of its great size, to have been permanent throughout geological time, except by those who have suggested that it represents the scar left on the earth's surface when the material that now forms the moon was torn away. This latter theory has now been conclusively disproved. It has already been suggested that some modifications in the shape of the Pacific have taken place, for the East Indies have been cited as the fragments of the former land continuation of Malaysia, which extended eastwards into the Pacific, and which persisted throughout Paleozoic time and until the Tertiary, at least in part. There was also a land connection with Australia until about the same time. But there is evidence that this ancient Malaysia also extended northwards to join an eastern land extension of China, called Cathasia, far out in the ocean. Farther south, it is extremely probable that Australia extended eastwards to include within one land-mass what are now the islands of New Zealand and Fiji. The northern part of the Pacific was also land, for there was a connection between north-east Asia and Alaska until at least the Tertiary Period.

There is a great deal of botanical, zoological and fossil evidence suggesting that there were extensive land areas in the Central Pacific, for example in the Northern Pacific in Eocene times. There is also some geological evidence for the former existence of a latitudinal sea stretching across what is now the Central Pacific, from Cambrian times to those of Lower Tertiary—the Pacific equivalent of Tethys. Many of the islands of the South Pacific possess coral reefs, and there are also many atolls. The most likely theory for the formation of such structures is that put forward by Charles Darwin, which postulates the building of coral rock on a slowly or intermittently sinking land which may be the coast of a continent, or an island. Corals can only live within very limited depths of water, so that the occurrence of great thicknesses of coral rock, in a position of growth, implies a sinking of the land on which it rests. This coral reef evidence would also point to considerable subsidence of the floor of the parts of the Pacific where such reefs and atolls occur.

There has probably always been an Australia, perhaps not in its present form and size, but a block of pre-Cambrian rocks that forms the present core of the continent. Between that stable block and the equally stable block of Asia there lay for long a great area of deposition, or a geosyncline. The deposits laid down in the geosyncline have since been folded and buckled, by movements which began in the early Tertiary Era, and which have gone on ever since. The prevalence of earthquakes and active volcanoes in the region now occupied by the East Indies show evidence of continuing movement. The result of the buckling was to bring some of the consolidated sediments above the sea as land ridges, and these have now been broken up to form two arcs or chains of islands between the two continents and separating the Pacific and Indian Oceans. The fact that great vertical movements have occurred in the region is also shown by the presence of raised coral-reefs, that is, reefs which were formed at and just below sea-level are now found several hundred feet above that level. There is also a belt of negative gravity about 100 miles wide running for a considerable distance between the island arcs. This indicates a downward bulge of lighter material into the heavier underlying sima. There would be a corresponding rise of heavier material along the edges of this belt, and gravitational measurements show that this is so.

There is some interesting biological evidence in favour of the recent former existence of land where there is now ocean, in both the Pacific and Atlantic regions. Three illustrations must suffice here; they are:

1. In British Columbia there is a species of plover which migrates every year over 2,300 miles of ocean to Hawaii, and returns every spring.

2. It has been noticed that every 10 to 15 years there is a large increase in the numbers of the lemmings—forest rats—in Scandinavia, and that when this increase takes place, the lemmings leave the woods, move downwards into the pastures of the western coastal districts, and then, still moving westwards, they plunge into the Atlantic and are drowned in vast numbers.

3. A similar periodic increase in the number of the springboks of South Africa has also been noticed, and they, too, exhibit this tendency to move westwards and so eventually into the South Atlantic.

All these phenomena receive an explanation if we suppose that there were land-masses to the west in each case in comparatively recent geological times and the ancient instinct to move westwards to those lands still remains in the creatures mentioned.

Life began in the oceans. The earliest fossils that have been found are all of creatures of marine habitat. And for the greater part of the time that life has existed on the earth it has remained in the waters. Not until Carboniferous times are there any great numbers of land plants or animals, although the earliest land plants appear at the end of the Silurian Period, about 350 million years ago. And still today, the oceans

are the homes of myriads of living forms of all types and sizes, from the whale down to the bacterial organisms. It may well be that the waters of the oceans still conceal living representatives of groups that flourished long ages ago, for in the deeps conditions do not change rapidly, and there would not be the competition that there has been amongst land animals and plants for survival, nor the catastrophic changes that have caused the dying out of whole groups that were once dominant, as for example the dinosaurs at the end of the Mesozoic Era.

CHAPTER X

THE VEIL BEFORE HER FACE—THE ATMOSPHERE

THERE is still one more sphere or envelope that surrounds Mother Earth, a gaseous one. We human beings, in common with all other life that exists upon the earth, dwell at the bottom of a vast invisible ocean, not of water but of gases. Life as we know it in its various forms can only exist because of that ocean, or to put it more scientifically, only those living forms have evolved on the earth which are adapted to an environment such as that of this gaseous mixture that we call the atmosphere.

Constitution of Atmosphere

The atmosphere consists, as almost every schoolchild knows, of a mixture of various gases—in the main, nitrogen and oxygen, but there are small quantities of others, too. The appended table gives an approximate average analysis of the atmosphere:

Gas	*Volume*	*Weight*
Nitrogen ..	78·03%	75·48%
Oxygen.. ..	20·99%	23·18%
Carbon dioxide	0·03%	0·045%
Argon	0 94%	1·29%

There are also present, in very minute quantities, a few rare gases, helium, krypton, neon and xenon. Water-vapour is also present in varying quantities, up to 4%. This last constituent is of great importance in many ways for its amount, termed the humidity, is the dominant factor in cloud formation and precipitation (which is the general word used to cover rain, hail, sleet and snow). One other constituent of the atmosphere is also always there, but it is not a gas—it takes the form of minute dust particles—the "motes" in the sunbeam. These particles are more numerous in the air over large cities and industrial centres. They are of great importance because they act as the condensation centres around which rain-drops form. It may be of interest to note that until a drop of rain in a cloud attains a diameter of 0.02 mm. it will not fall.

Although the constitution of the atmosphere—despite the fact that it is a physical mixture—is remarkably constant, the same is not true of its other properties, such as pressure and density. It is estimated that at least one-half of the material in the atmosphere is contained in the lower

three and a half miles, whereas the outer limits of the air-ocean probably reach out some 200 miles from the earth's surface. At high levels, therefore, the atmosphere must be very tenuous. This fact raises many problems for high altitude flying. As with the stony envelope of the earth so with the gaseous, there is a stratified structure. Observations have shown that as one ascends into the atmosphere there is a fairly steady fall in pressure and in temperature. The fall in pressure is not uniform and depends on the temperature as well as on the height above ground, but in round figures it may be said that the barometer falls about nine inches for the first 10,000 feet ascended, when the ground temperature is 60°F.

This fall in pressure with increasing altitude is made use of in the altimeter fitted to the instrument board of an aeroplane—this is an aneroid barometer of which the face is graduated in feet and not in the usual inches. The scale is movable so that the pilot can set it at zero before taking off, and he thus has then allowed for variations from the normal in temperature and pressure at his aerodrome. The reading on the altimeter shows the difference in height between his taking off place and his position in the air at any given time; it is obvious that unless he sets his pointer at zero before starting the reading will not give a true record of his height above the ground. This falling off in pressure with height is also made use of in preliminary surveying of a country.

Anyone who carries an aneroid barometer with him in a car on a trip that entails a good deal of hill-climbing will notice the fluctuations of the needle, and if these are plotted on a graph together with the distance travelled, a curve will be traced out that corresponds to the surface travelled over. Modern instruments give an accuracy up to about five feet in vertical height.

On the other hand, the fall in temperature with increasing height is fairly uniform, at least for a distance up into the atmosphere. The fall is about $3\frac{1}{3}$°F. for every 1,000 feet ascended, and this continues uniformly until a certain level is reached—this level, which is called the tropopause, is about 7 miles up in our latitude, about 11 miles at the Equator and only 4 at the Poles. (See Fig. 20.)

That part of the atmosphere lying below the tropopause is called the troposphere and it is in that lower stratum that varied weather is experienced, for only in it are there any clouds or any great vertical differences of temperature sufficient to produce condensation and precipitation. Most of the winds produced by variations of pressure and temperature are also to be found in this lower level. This is a different state of affairs from that existing in the aqueous ocean, for there it is the surface layer that is subject to most variation and movement. Before considering in greater detail the features of the lower atmosphere it may be best to complete a sketch of our knowledge of the upper air, of which as yet we know little.

Above the tropopause is a stratum known as the stratosphere, in which,

as one ascends, there is very little or no falling off in temperature—there may be horizontal variations of temperature but not vertical. The stratosphere is coldest where it is highest, that is, over the Equator, and the temperature falls as one passes towards the Poles. The actual

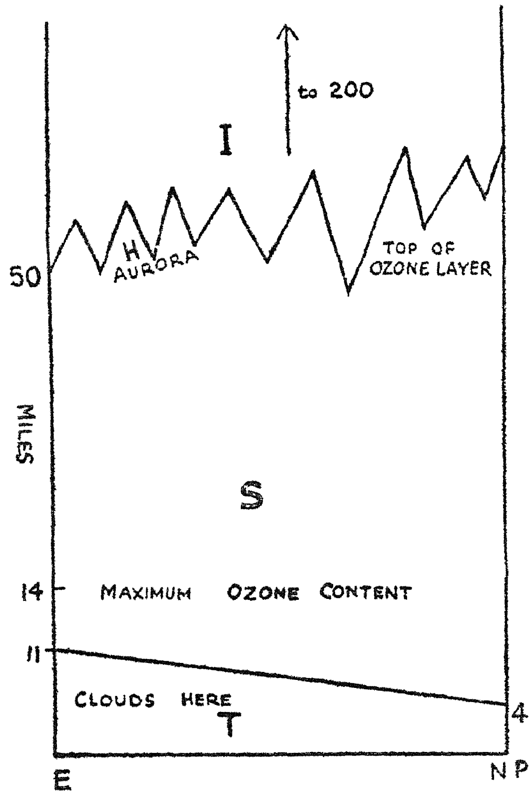

FIG 20 VERTICAL SECTION THROUGH ATMOSPHERE

E = Equator
T = Troposphere (tropopause at top)
S = Stratosphere
H = Heaviside Layer, which reflects radio waves
I = Ionosphere, which extends upwards about 200 miles

temperatures will naturally be very low, about 120°F. below the surface temperature. The pressure, too, is very low and the amount of oxygen low, hence oxygen masks are needed, or pressure cabins and electrically warmed suiting are required for stratosphere flying. It is probable that at about 30 miles altitude there is an ill-defined layer containing much

ozone. This layer is believed to absorb 4% to 5% of solar radiation, so that that layer would become heated. The upward limit of the stratosphere is very irregular and lies anywhere between 50 to 60 miles up.

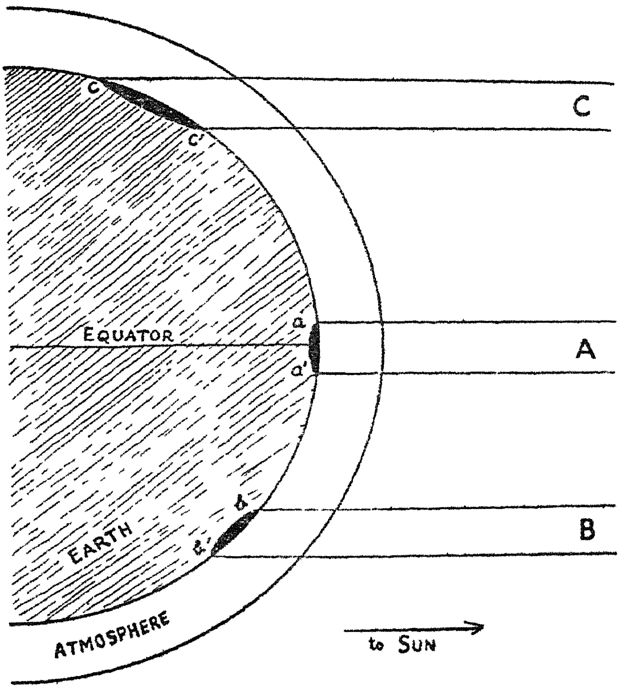

FIG 21. EFFECTS OF EARTH'S SPHERICITY ON INSOLATION

The intensity of solar radiation (light and heat) varies with the latitude Three bundles of radiation, A, B, C, all of same amount, pass through varying thicknesses of air and cover differently sized areas of the earth's surface (a—a, b—b, c—c), so that the same amount of radiation is concentrated into a smaller surface area when the sun is immediately overhead (equator in diagram) and loses less by absorption and scattering (because thinner layer of air has to be passed through) Result is that intensity of insolation decreases as latitude increases

Above this upper limit there is the ionosphere, so called because the air in it is ionized, i.e. the molecules and atoms are electrically charged. For this reason the base of the ionosphere or Heaviside Layer reflects the longer wireless waves and so this makes it possible for listeners to hear a radio station on the side of the earth opposite to them. Some 150 miles up, i.e. well into the ionosphere, there is believed to be another reflecting

layer, the Appleton Layer, which reflects the short wireless waves. O the constitution of these higher atmospheric levels we know very little direct observation is obviously impossible and indirect evidence gaine from study of such upper air phenomenon as the Aurora Borealis (whic occurs above the Heaviside Layer), has been interpreted in various way by different observers.

Movements in the Atmosphere

It will be recalled that in the case of the solid crust there are variou movements set up as a result of temperature differences and changes an that those movements fall into two groups—horizontal and vertical. S it is with the atmosphere, the temperature differences over the earth' surface (see Fig. 21) cause pressure differences, according to the genera laws dealing with the behaviour of gases. These pressure differences ar shown in a very generalized way in Fig. 22, where also is shown the mai winds which blow from the areas of high pressure to those of low (thos are the horizontal movements).

The general scheme of pressure and wind distribution is subject t many modifications. Firstly, the inclination of the earth's axis to th plane of the ecliptic results in an apparent swing of the sun across th Equator from the Tropic of Cancer to that of Capricorn. That mean there is a seasonal oscillation of the heat-equator, and since it is this whic determines the other pressure-zones, those shift too.

Other important modifiers of the general plan are the distribution c land and sea (land heats up more quickly and loses heat more rapidly tha does the sea), the development of local centres of low pressure, especiall within the belt of the "Westerlies" (these are the cyclones or "depressions which move north-east across the North Atlantic and are responsible fc most of the cloud and rain of Britain); local high pressure centres, or ant cyclones, may also become detached from the high pressure belt over th Azores and move north-eastwards too. These, in their turn, also affe the weather of this country, in general, they bring fine weather and settle conditions.

The vertical movements in the atmosphere are very important. The are due to the fact that "hot air rises", as can be seen in the heat-ha over any pavement or roadway on a hot summer's day. It is this vertic movement above warm surface areas that results in the horizontal inrus at low levels, which are the winds. These upward currents also cause th clouds, for as the hot air rises, it cools and eventually may reach a ten perature low enough for the contained water vapour to condense out in minute droplets and so form cloud. This process can be seen on a sma scale when a kettle boils in a room for some time, clouds forming und the ceiling. Clouds, after formation, are borne away by winds ar eventually discharge some of their contained water as rain. Not only c

the clouds act in this useful way, but they also form a blanket which prevents undue radiation of the surface heat. In hot deserts where the skies are cloudless—although there is little seasonal difference in the day temperatures—there is a very marked temperature difference between day and night because the cloud blanket is absent. The atmosphere, as a whole, also acts in this way. If it did not then there would be

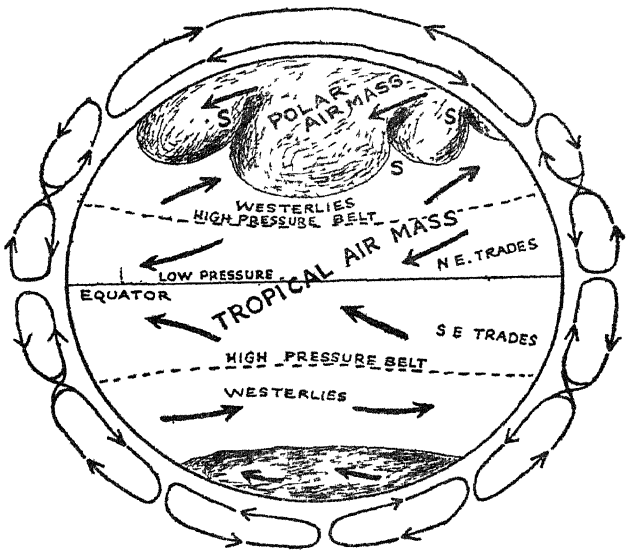

FIG. 22. AIR MASSES

Land and sea masses disrupt symmetry of pressure distribution, and hence of wind circulation Northern continental interiors retain less of sun's heat than do the oceans, therefore north polar air mass is displaced so that its centre lies not over North Pole, but over N Asia, and the cold air flows southwards over land More symmetry is seen in case of South Polar Mass Cloud manufacture takes place in eastward moving storm-waves which are generated in ebb and flow of Polar air-mass (S=storm-centres)

exceedingly high day temperatures when the sun's rays were beating down, and exceedingly low temperatures at night when the surface would radiate away its heat very rapidly.

Such conditions prevail, for example, on our satellite, the moon. Not only would these great temperature differences be inimical to life as we know it—which can only exist in a very restricted set of conditions—but there would be very rapid disintegration of the surface rocks with the production of a type of scenery much more angular and jagged than that

with which we are familiar. In fact, the earth's surface would resemble as a whole that scenic type which is now limited to the narrow limits of high mountains and those hot deserts where the bare rocks are not covered by sand or earth.

Atmospheric Effects

Other natural beauties would be absent, too, in an airless world, for example, there would be no rainbows or gorgeous sunsets. The former are produced by the breaking-up of the white light from the sun into its seven constituent colours, by water droplets in the atmosphere, the latter are caused in part in the same way and also by the fact that the setting (or rising) sun is shining through a greater thickness of the atmosphere and, therefore, more of the blue light waves are absorbed, with a consequent tendency to result in red and yellow colours. The Aurora Borealis, too, is a photo-electric effect produced in the upper levels of the atmosphere. As a matter of fact all the colour effects seen in the sky, including the commonest of all, blue, are formed by the atmosphere, which, with its contained water-vapour and suspended dust particles, breaks up the white light from the sun.

On an earth that had no atmosphere there would be no sounds to delight or annoy us—no bird-chorus at dawn, no voices, no music—for sound is merely a vibratory motion in the air or other medium, and can only be transmitted from the source to the receiving ear when there is some medium in between. And the most usual medium for that transmission is the atmosphere.

Clouds

Since the most visible features of the atmosphere are the clouds a little may be said about them. Their mode of formation has already been described, and their movement with the winds. Anyone can form artificial clouds by allowing a kettle of water to boil, when the steam will condense out as a mist or cloud in the upper part of the room. Another illustration of "cloud" formation can be seen on a frosty day when one's breath—saturated with moisture—condenses into puffs of mist in the cold air. The upward thermal currents produced by heating of the earth's surface, or the upward deflection of air masses by hills or colder denser masses of air (over which the warmer less dense air rises), are the agents which keep the clouds up. Although it seems at first glance that no two clouds are alike, it is possible to make a classification of them, and this depends on the heights at which they are formed. The following table lists the more common types:

HIGH CLOUDS (forming at 25–35,000 feet)	Cirrus. Cirro-cumulus (mackerel sky) Cirro-stratus.
MIDDLE CLOUDS (forming at 10–25,000 feet)	Alto-cumulus. Alto-stratus.
LOW CLOUDS (forming at heights below 10,000 feet)	Strato-cumulus. Stratus. Nimbo-stratus. Cumulus.
Cumulo-nimbus clouds may occur at any height up to 25,000 feet	

A few explanatory notes are also given below:

Cirrus clouds—detached, delicate, fibrous clouds, generally white in colour, occurring tufts, lines, plumes, etc. Wispy looking. Include the "mares' tails". Actually formed of ice particles owing to their height.

Cirro-cumulus—cirriform layer or patch, made up of small white flakes or very small globular masses, arranged in groups, lines or ripples.

Cirro-stratus—thin whitish veil which does not blur the outlines of sun or moon, but gives rise to haloes. May be so diffuse as merely to give the sky a milky look.

Alto-cumulus—layer or patches composed of slightly flattened small and thin globular masses.

Alto-stratus—striated or fibrous veil, more or less greyish or bluish in colour. Sun or moon shows faintly through without halo.

Strato-cumulus—layer of globular masses or rolls, soft and grey with darker parts.

Stratus—a uniform layer of cloud resembling fog but not resting on the ground.

Nimbo-stratus—low, amorphous and rainy layer of cloud of dark grey uniform colour.

Cumulus—thick clouds with great vertical development, with upper surfaces domed, turreted, with rounded protuberances, and bases nearly horizontal. These clouds have well-defined boundaries and are white with some shading. Typical clouds of a warm summer's day.

Cumulo-nimbus—heavy masses of cloud with great vertical development, upper parts rise in mountains and turrets, and edges may be fibrous. Greyish in colour, except where lit by direct sunlight. Generally give rise to rain or snow.

There are, of course, numerous variations on the above and clouds often grade from one type to another. It is this change in type that is

made use of in weather forecasting. A single glance at the cloud formation will not give much indication of coming weather, but continued observation may do so, for example, if cirrus becomes thicker and lower then it is likely to rain. It is the development of the clouds and not their appearance at any one time that is useful in this connection.

To conclude this short chapter, here are a few figures. The mean diameter of the earth is 7913·33 miles, hence its surface area is $1{\cdot}969 \times 10^8$ square miles. Since the weight of the atmosphere is equivalent to that of a layer of mercury 29·92 inches thick (the average height at which the barometer rises at sea-level), and the density of mercury is 13·5, the mass of the atmosphere is $5{\cdot}2 \times 10^{15}$ tons. The mass of the earth is $5{\cdot}89 \times 10^{21}$ tons, so that the solid earth is 1,130,000 times as heavy as the gaseous envelope that surrounds it.

Note to Chapter x

The Weather

It may be of interest to say a little more about the weather since that of all things connected with Mother Earth is the most discussed and very little understood by the man-in-the-street. In fact, it is only within the last two decades that any real knowledge of it has been won. It was once supposed to be unpredictable—at least as far as Britain was concerned—it was considered to be local. Despite our progress it still remains true that the weather affects for good or ill the lives of the great majority of men and women, certainly that 65% of the population of the world that is engaged in agriculture. The changeable weather of the temperate regions has played a great part in stimulating enterprise and energy and invention.

Today, as a result of the frontal and air-mass theory of weather developed during the first world war by the Swedish meteorologists, Bjerknes and Solberg, we are beginning to make the weather make sense. Today we know that there is no such thing as local weather, the forces that generate a storm over Britain are linked with those that determine the weather over New York or Verkhoyansk. The weather of the world is determined by the constant orderly circulation and movement of the whole atmosphere. The first glimmer of this truth was seen 200 years ago by Benjamin Franklin when he discovered that one particular rainstorm that affected Philadelphia moved on up the coast to drop rain on New England. Today, with radio and cable it is easy to follow the track of storms and so forecast them, too.

It has already been stated that the gases of the atmosphere obey the general gas laws, that is when warmed (by the sun) they expand, become

less dense and rise, whilst cooled air contracts, becomes denser and sinks downwards. Warm air can contain more moisture than cold air, so that if warm moisture-laden air is driven upwards by a hill or mountain slope or over a mass of cooler air (which acts as a hill would do, for air-masses of different temperature do not readily mix, except at the plane of junction), it will cool and condensation will occur, first in the form of cloud and, if the condensation continues, there may be precipitation in the form of rain.

The primary force in the circulation of the atmosphere is the heat of the sun and the intensity of this varies with the latitude, thus resulting in a vertical movement of air over the equatorial region, an outward, Pole-ward movement in upper levels and then downwards at the Poles and so back to the tropics again. But this simple circulation is complicated by the rotation of the earth and the distribution of continents and oceans, with the result that the solar-heat circulation breaks up into zones of circulation and the atmosphere into separate air-masses which assume characters dependent on the regions in which they are formed. The two

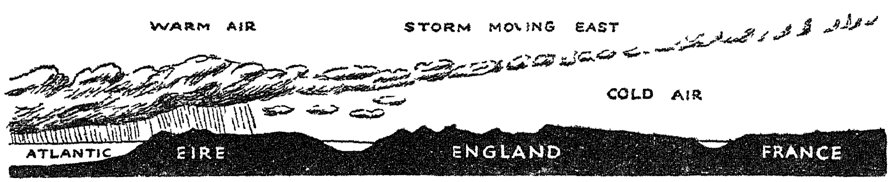

FIG 23 WARM FRONT STORM

As storm moves eastwards so cloud sequence moves over Britain Rain zone over Eire moves east, too Vertical scale exaggerated Cirrus clouds, over France above, form at about five miles up.

main masses that affect the northern hemisphere are the polar air mass and the tropical air mass, the former overlies the northern land-masses of the globe and is cold and dry in comparison with the latter mass which, overlying the tropical oceans of the northern hemisphere, is warm and moist.

The simple fact that the atmosphere is composed of different kinds of air is the basis of the air-mass theory of weather. When the warm mass meets the cold one, it rises above the colder air, or tends to do so. The boundary of the cold mass is called the polar front, and this is always changing in position with the seasons. Along this front the two air-masses are in perpetual conflict. As the warmer moist air rises over the colder there is condensation, cloud formation and rainstorms, and the eddying set-up results in barometric variations so that there arise local centres of low pressure—the depressions of the weather reports. These local centres, caused by the waves at the edge of the polar front, move eastwards across the temperate zones of the Northern Hemisphere for thousands of miles, thus it is that the rainy weather of Britain comes in from the Atlantic; that is why "deep depressions" over or south of Iceland were so ominous when heard in the weather forecasts, for they meant rain and bad weather

for Britain to which they were on the way. That is why, too, during war it was important not to publish weather news, for our storm weat moves on eastwards over Europe.

The storm begins as shallow waves or surges in the polar front a deepen into vortices and then eventually rise above ground level; wind circulation within them is anti-clockwise and therefore ground-le winds change direction as the storm passes across a given district. Th

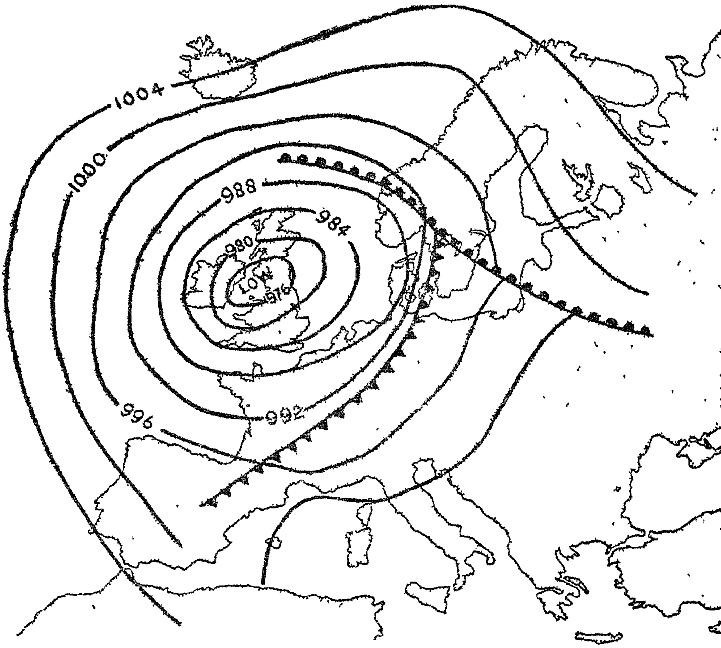

FIG 24 DEPRESSION
Thick lines are isobars. Figures are millibars, 1,000 = approximately 30 ins mercury Line with rounded markings is edge of a warm front Line with pointed markings represents a cold front

is, as shown in the diagrams, usually a regular and characteristic clo sequence which together with barometric observations—a falling glass helps in forecasting the advent of such storms, although the size of t storm or its intensity can only be learned by reports from areas over wh the storm travels before it reaches us.

Just as there is a no man's land between fronts in war, so there is c in this ceaseless conflict of the air-masses, a region of the earth's surfa where neither one nor other of the masses becomes established for a length of time. The British Isles lie in such a no man's land, that is w our weather is so changeable. Increasing knowledge of the atmosphe

especially of the circulation, and increasing numbers of reports coming in from stations to the west (usually ships at sea), are making our weather reports and forecasts much more accurate. In the case of a country like the United States—parts of which lie in a similar no-man's land—the ability to forecast is made easier because there is such a large land area from which numerous reports of local weather conditions can be collected practically simultaneously, so enabling an over-all picture to be accurately built up.

The periods of stable weather which we do get are nearly always associated with the anti-cyclones referred to above, and are due to the fact that at such times one or other of the great air-masses has temporarily driven the other away and established itself over the British area. These stable periods may occur in summer or winter, if in winter then the polar mass is in occupation of the disputed ground, if in summer, then the tropical air-mass is temporarily in the ascendant over Britain.

CHAPTER XI

MOTHER EARTH'S CHANGING DRESS

We have now described the many skins, or envelopes—solid, liquid and gaseous—which, onion-like, make up the earth, but there is still another which merits some attention. Like all ladies, Mother Earth wears an outer garment which she changes from time to time, from season to season. This cloak, or envelope, is, as Dr. Arthur Holmes says, "a less familiar conception, it is the biosphere, or sphere of life".

> "Think" (writes Dr. Holmes in his *Principles of Physical Geology*, pp. 8–9) "of the great forests and prairies with their countless swarms of animals and insects. Think of the tangles of seaweed, of the widespread banks of molluscs, of reefs of coral and shoals of fishes. Add to these the inconceivable numbers of bacteria and other microscopic plants and animals. Myriads of these minute organisms are present in every cubic inch of air and water and soil. Taken altogether, the diverse forms of life constitute an intricate and ever-changing network, clothing the surface with a tapestry that is nearly continuous. . . . Such is the sphere of life, and both geologically and geographically it is of no less importance than the physical zones."

Those of us who are fortunate to live in England, and especially in her lovely western shires, know something of the ever-changing vesture of plant life that cloaks the otherwise naked surface of the crustal rocks. The countryman, at least, sees the varied robes with which Mother Earth bedecks herself. If, as some supposed, the wider lines and markings on the face of Mars were evidence of strips of vegetation that thrived alongside the imagined canals, how much more must the plant life of the earth show up in variegated pattern from out in inter-planetary space? The aesthetic difference alone that the biosphere makes can best be pictured by comparing some region of the earth where plants thrive—the jungles of Burma, the wheatlands of Canada, the vast woodlands of Siberia, or the jig-saw puzzle of our English fields and hedges—with those where the bare rock or its weathered debris forms the surface, as in the deserts of Australia or Atacama. If there were no biosphere then Mother Earth would present as bare a face as does her daughter, the moon.

But it is, of course, the geological and geographical aspects of this sphere that are so important for human life, and to a brief consideration of these we now turn. But first, let it be noted that the biosphere is one with no well-marked boundaries, it penetrates and links the lithosphere, the hydrosphere and the atmosphere. Plants grow in the soil, yet need the water and the atmospheric gases, and animals need plants for their sustenance, as well as water and air. The biosphere is a sort of common

factor, in fact life can exist in earth or air or water provided all these interpenetrate as indeed they always do unless the earth and water are permanently frozen and then it is difficult for air to permeate into them.

Biological Action on the Crustal Rocks

We have already seen how the agents of weathering and erosion slowly but surely wear away the surface of the land, by disintegration and transportation, but their action is very much restricted if there is a coating of vegetation on the surface. This is shown by an observation of streams in forested regions; it will be noted that such streams are nearly always clear, that is there is little material being carried away. If the trees are felled then the water becomes clouded and muddy. The crumbling of the face of rocks in desert regions, as a consequence of the alternate heating during the day and cooling at night, does not take place in areas where there is a protective coating of vegetation over the rocks. The matted rootlets of grasses and other small plants help to bind the surface soil and so prevent its loss through weathering. Many areas which were once covered with sand-dunes that were always shifting with the wind, have now been reclaimed by planting the sands with various types of grass that bind the grains. Pasture land can be utilized on slopes that are so steep that if the land were arable, the rains would wash away the soil. Vegetation also helps to conserve moisture in the soil and so assists in soil-fertility.

On the other hand, the roots of trees often play a great part in breaking up the surface rocks immediately under the soil. This sort of thing can often be seen at the tops of cliffs and cuttings, where large roots push down into crevices, which they gradually enlarge and so prise off chunks of rock from the cliff face. Some roots, for example ivy, secrete acid solutions which dissolve limestone and other calcareous matter, and this reinforces the splitting action of the roots. Worms and other burrowing animals, such as rabbits and moles, bring up fine particles of soil to the surface—small piles of really good fine soil can be seen outside any burrow, or above any mole-heap—and this material is easily removed by wind and rain, and so the soil becomes impoverished. It is for this, amongst other reasons, that agriculturalists wage a continual war against rabbits and moles.

Many simple types of plant, such as fungi and the lichens, contribute to chemical weathering because they act upon the soil minerals and abstract substances from them. Water that is full of bacteria is more easily capable of dissolving mineral matter than water without them would be. Decaying plant and vegetable remains in the soil liberate carbon dioxide (which in water forms a weak acid), organic acids, ammonia and nitric acid, and these all help in the break up of mineral matter in the soil. But there can be little doubt that one of the principal organic agents in the

destruction of the earth's surface is man himself. Reference has already been made to the ravages of soil erosion consequent on man's bad farming methods and his slaughter of the trees, which are Nature's insulators against extremes.

On the other hand, the plants and animals of the world have played a part in construction as well as in destruction from the geological point of view. All the carbonaceous rocks are of organic origin. Most people are familiar with the fact that the great seams of coal are composed of the remains of great forests that grew in past geological ages, principally the Coal Measures. The plant material has been subjected to great pressure and undergone changes with the result that today, most of the lighter constituents of the tissue have gone and only the carbon remains together with stony impurities. But what is perhaps not so well known is the fact that the great petroleum deposits of the world are also of organic origin.

There has been much debate about the origin of natural oil, and the fact that there are no visible traces of original material, as is the case with coal, makes a solution of the problem more difficult. But there are several pointers that indicate an organic origin; for example, natural oils contain substances that polarize light (and this is only done by organic substances). Again, natural oil never occurs associated with igneous rocks—70% of the world's oilfields occur in sedimentary rocks of Cretaceous and Tertiary age. In the dying-out stage of an oil-field there is a good deal of briny water pumped up with the oil, this seems to suggest that the oil is of marine origin. Recently, samples of deposit dredged from the floor of the Black Sea were found to contain 25% matter of organic origin, and 10% hydrocarbons—this seems to be an early stage in the formation of natural oil actually going on at the present day. The conclusion to be drawn from the available evidence is that natural oils originate as a result of the decomposition of organic matter, principally plant remains, by the action of bacteria, in the absence of oxygen, the whole being incorporated with other sediments in depressed regions of the sea-floor.

Life as a Rock-forming Agency

But for sheer amount of material added to the rocks of the crust by biological action one has to turn to the limestone rocks, many of which are composed almost entirely of the remains of animal skeletons and shells The Chalk which forms so much of southern England is made up, in the main, of the minute tests or skeletons of myriads of small marine creatures the Foraminifera, which swarmed in the seas of the Cretaceous Perioc when that rock was formed. The Nummulitic Limestone of Egypt whicl was used in the building of the pyramids is another rock that is compose almost entirely of the disc-like shells of another lowly organism.

Throughout the warm seas of the Tropics today, as in the past, whol islands as well as great reefs are being built up by the coral polyp. To tak

but one example, the Great Barrier Reef of Australia extends for 1,200 miles along the north-east coast of that continent, with a varying width of many miles, and with a thickness of hundreds of feet in places. Other rocks which are not obviously composed of skeletal remains, such as the well-known oolitic building stones of the Cotswolds, yet owe their origin to biological action, for it seems likely that the precipitation of lime in the small spheres, which, tightly packed, make up the oolite (hence the name, which means "egg-like", or like a fish-roe), was due to bacteria action. Similar action is producing extensive calcareous deposits in the shallow seas that border Cuba and the Bahamas at the present day. Bacterial action of this kind is also responsible for the precipitation of certain ores of iron, e.g. limonite, from lake and marsh waters, as in existing lakes in Sweden and Finland, where the deposits so formed are of economic value.

The biosphere is of value in another way, too, for it was the action of plants under the influence of sunlight that produced free oxygen. There would have been none in the original atmosphere of the earth, it would have been combined with carbon to form carbon dioxide. But plants have the power to break that compound down, releasing the free oxygen and using the carbon in building up their tissue. That is why coal and oil, made from the decay of plant matter, contain so high a proportion of carbon. If there were no free oxygen then animal life as we know it would have been impossible, and further, many of the break-down processes to which rocks are subject through weathering, many of the changes in mineral structure and composition, are dependent upon a supply of free oxygen.

Geological History of the Biosphere

Although the conception of the biosphere is somewhat unfamiliar, yet the surface effect of some living things, notably the plants, is so obvious that little more need be said about it, but it may be of interest to look back into the past history of the earth and see what we can learn about the biosphere then. We have already noted that many of the rocks of the crust are composed very largely of animal and plant remains, but there are also many other rocks which although not formed by biological action yet contain fossils, which are the remains or traces of once-living forms of life, and which in general were living at the time that the rocks that contain them were laid down. From these fossils we are able to reconstruct the life of the past geological periods and so picture something of the plants and animals that then existed, and of the changing dress of Mother Earth. It is from these records of the rocks that the story of evolution has been, to a great extent, reconstructed, that story which tells how as we go back into the past there were simpler and fewer living types. Although the full story is outside the purview of this book, it may

be of interest to note, in connection with the biosphere, one or two points from it.

Far back in the early Paleozoic Era there were no land-dwelling forms of life, all life was then confined to the seas, there were no plants to clothe the surface with a carpet of greenery, so that the terrestrial landscape must then have resembled that of the moon today, to this extent, that it was bare rock surfaces, with heaps of scree and sand. Not until towards the close of the Silurian Period did the first plants begin to appear. By the Carboniferous Period, plant life had become luxuriant in some regions, as the coal-seams bear witness, for they are the fossilized remains of such life. But although there were great stretches of tropical marshy "forests" in that period, clothing the earth with a cloak of vegetation, there would have been but little variation of colour, other than shades of green. For it was not until much later, in the Cretaceous Period, that the first flowering plants became at all numerous, before then plants had been mainly of the "fern" or conifer type.

Little need be said, under this heading, of the changes that have occurred in animal life, for the more marked changes in the biosphere cloak are caused by the plant life, whether it be individual or collective growth. The largest animals that have ever lived upon the earth—the amphibious Dinosaurs in the Mesozoic Era—although some of them were over a 100 feet in length, are small compared with the largest plants, the giant Sequoia, or redwood trees of California. These trees often attain a height of 300 feet. Collections or groups of animals may, as in the case of corals, form great masses of calcareous rock, but the greater part of such masses are hidden beneath the waters of the oceans and even if they were completely exposed to view—with the possible exception of the Great Barrier Reef of Australia—they would compare badly for size with the great coniferous forests of the cold temperate regions or with the jungles of the equatorial regions. In fact, viewed from outer space, even no farther away than the moon, all that could be seen of life on the earth would be the plant assemblages, the forests and the great grasslands. There would be but one exception, and that an indirect result of one form of animal life, the great cities—London, New York, Berlin, Tokyo, etc.—which would stand out as darker blotches against a general variegated background of blues, greens and greys.

There is an old saying that runs, "God made the country, but man made the town", and it is true, in general, that the natural processes of evolution have produced the biosphere which does so much to cloak the otherwise bare face of Mother Earth with its everchanging tapestry of colour. Yet there is one great exception that may be noted here. We, in England, tend to think of the jig-saw pattern of fields and hedges as natural and typical of the countryside, but such is not the case. That pattern is comparatively recent, and is the work of man. It dates from about the eighteenth century when the enclosure of the one-time common lands reached its climax. Before then, far back in Anglo-Saxon times,

most of Britain was covered with woods. Gradually the woods were cleared, meadow-lands grew in extent around each settlement, but they were hedgeless and widespreading, the land was park-like in character, the clearings were held in common by the people of the villages, but a change was to come. From some points of view that change might be deplored, but from the aesthetic standpoint there is little to grumble at, the little fields of England which gave our country the appearance of a patchwork quilt when viewed from above are loved and lovely at all seasons. Man does not always mar the face of Mother Earth when he tries to alter her costume and her make-up.

The stone walls of the limestone uplands of Cotswold and elsewhere, the brown earth of ploughlands and the green patches of pasture, the little plantations that harbour game birds, all these are man-planned and man-made, and all help to make up that kaleidoscope of colour and variation of detail that is the English countryside. Mother Earth cannot now, as once she did, evolve alone her own clothing, for she has reared a species of mammal, some of whose members, for good or ill, now determine in no small degree what clothing their parent shall bear, and that process of change must inevitably continue. The widespreading forests of Canada and elsewhere are disappearing as man fells more and more trees to make the pulp from which the books are made that tell, amongst other things, the story of Mother Earth.

CHAPTER XII

HUMAN ACTIVITY IN AFFECTING THE EARTH

It is calculated that there are, approximately, 2,000 million human beings living on the earth. It seems a very large number, but when we consider the surface land area of the earth, it will be seen that there is no fear of overcrowding for long yet. There are 57,510,000 square miles of land, so that the average population is but 35 per square mile, or one individual to each 88,528 square yards of the land of the world. The whole population of the world would find comfortable standing-room on the Isle of Wight!

This population is very unequally divided; for example, Europe, with an area of three and three-quarter million square miles has an estimated population of about 500 million, whilst Australia, with an area of three million square miles, has a population of but 7,100,000 (1941). That is, the population is about 60 times as dense in Europe as in Australia. Even in Europe there are countries that are sparsely populated; Holland, for example, has about 680 people to the square mile, whilst Sweden averages but 34 to each square mile.

The best estimates put the period of human occupancy of the earth as about 50,000 years, that is, of man as he is today, the species *Homo sapiens*. It seems likely that sub-human and transitional forms, from non-human to sub-human, existed for a much longer time; in fact, some authorities would put the emergence of the first creature that was at all human-like, as far back as half a million years. This may seem a lengthy period, but compared with the age of the earth, man's tenancy of it is very short. (See Chapter VI.)

In this book the main interest is with the earth as a body, and not with the living population, except in so far as living creatures have affected the surface of the earth. Yet since man, although so recently evolved, has produced many topographical and other changes, something must be said of his activities in this connection.

Many districts once almost level and plain-like in character have been diversified by small artificial mounds or hills through the industrial activities of man, for example, the "dirt heaps" and slag mounds that are formed where mining operations have taken place. The traveller who passes through the coal-fields of South Wales or the Ruhr, for instance, cannot fail to notice the mounds, often of considerable size, that have resulted from the dumping of waste material brought up from underground in the winning of coal. The huge white conical mounds so characteristic of the north Cornwall district are formed of the accumulation of the waste material from the china-clay quarries that fringe the granite masses of that county.

When, as usually happens after a lapse of time, these man-made hills become covered with vegetation, then they do seem, at first glance, to be of natural origin. Many of the barrows, or burial mounds which dot the surface of the limestone uplands, such as the Cotswolds, or the Chalk plain of Wiltshire, are sufficiently large to stand out distinctly from the surrounding countryside, some are 20 feet high and 50 feet long. In fact, the largest artificial hill in England, perhaps in Europe, is the well-known Silbury Hill, near Avebury, in Wiltshire—its purpose is still not clear. This hill, whose base extends over five acres, is in the shape of a truncated cone, reaching to a height of 125 feet, and would therefore be mapped as a hill on the ordinary contour maps of the Ordnance Survey. It was erected by the men who built the neighbouring stone circles of Avebury, during the Neolithic Period, or New Stone Age, probably 2000 B.C.

Mining activities produce other topographical changes. Drainage is often affected as a result of underground working, streams may be diverted or reduced in size, whilst in salt-mining districts, such as the Cheshire Plain, small lakes, or meres, are produced by water filling the holes from which the mineral has been dug. Lakes, often of considerable size, are formed by damming operations, either in connection with the formation of reservoirs to supply large towns, or in order to maintain a sufficient head of water to drive turbines to produce electrical power. The City of Birmingham, for example, draws its water supply from the reservoirs, or lakes, formed by damming the valleys of the Elan and the Claerwen rivers, near Rhayader, in mid-Wales. Lakes produced in this way are often larger than those naturally formed in the same district. For example, the 504-acre Ladybower Reservoir opened by the King in 1945 has greatly altered the scenery of the Peak District of Derbyshire, for there is no large natural lake in the district.

On the other hand, man has turned areas that were once covered with lakes and marshes into drained and tillable land. The Fens were once a tract of marshland, covered with rushes and other aquatic plants, intersected with slow-moving streams and shallow lakes, formed by the silting-up of a great bay of which the Wash is the last remnant. Draining of the area was begun by the Romans during their occupation of Britain, but little was really done until 1634 when Francis, Earl of Bedford, and thirteen others reclaimed the tract known as the Bedford Level, of 95,000 acres; by 1807 the work of drainage in the Fens was complete and a tract of country some 70 miles in length and 35 miles in the widest part, and 100 square miles in extent, was turned into some of the richest agricultural land in the country.

Great areas in Holland have likewise been reclaimed, especially parts of the Zuyder Zee, that large shallow lake, or inlet, which was washed out in great floods in 1170, and much of which was won back as a fertile tract. The reclamation of the erstwhile marshy and fever-ridden tract

of the Pontine Marshes, near Rome, remains as one of the few good things done under Fascist rule in Italy.

Man has thus helped Nature, in some ways, in enlarging the land areas, whilst in other places he has, by the construction of sea-walls and groins, prevented natural agencies from eroding away the coasts. In this way, and by planting special species of grass on dunes and sands to bind the grains and prevent wind erosion, much land has been saved for the country. It has been estimated that in the course of the past 300 years some 230 square miles of new land have been added to this country alone.

Even climatic conditions have, in some instances, been changed by human activity. Where there are vast forests the rainfall is usually heavy, but when those forests are cut down, or much reduced in size then the annual rainfall decreases. Such a change has occurred as advancing civilization has destroyed the forests that once covered the whole of the Mediterranean littoral, or the greater part of Britain, excep for the higher limestone uplands. It is computed that the annual rain fall in Britain at the time that the Romans invaded the land was some 50% higher than it is today—and we grumble about the wet weathe today! This former greater rainfall is attested to by the fact that camps and settlements were constructed at heights to which the water table (o level of permanent saturation of the rocks) does not attain today. This deforestation has had—as discussed more fully in Chapter VIII—probably a greater effect in altering the surface of the earth than all the othe activities of man.

Oceans and seas have been artificially joined by the cutting of canal through narrow isthmuses, for example, the Panama Canal which links the Atlantic and Pacific Oceans. This may result in the passage o living forms from one area to another, marine creatures which had hitherto been prevented from occupying new areas because of the land barriers. For example, organisms living in the warm seas of the Gul of Mexico could not have travelled around Cape Horn and up the westen coasts of South America because they would not have survived in the colder southern waters, but they may be able to migrate through the Panama Canal whose waters are of similar temperature to that of thei natural habitat.

The construction of inland canals must also alter the appearance o a country, in fact aerial photographs show that such constructions are often distinguishing features of a given area and are a great aid in identifying a district since they run so much straighter than do the natural streams or rivers.

The aggregation of men and women into large cities has also given rise to new features, even if undesirable ones from the aesthetic poin of view, on the face of the earth. Great wens—as large cities such a London have been termed—covering many square miles, would be visibl from well out in space. But there is not only actual buildings, there is th

change wrought in the natural vegetation of the surrounding districts by the great cities, especially if those are industrial centres. There is pollution of the atmosphere with dust and smoke which tends to reduce vegetation.

A journey through the Black Country—well named and from this very reason—will suffice as an illustration of the undesirable changes human activities can produce. Perhaps the increased use of electricity as a source of power will have some effect in staying the destruction of plant life, and the consequent impoverishment of the soil.

Great cities also produce changes in the atmospheric conditions, too, for the abundant dust particles in the atmosphere above such places induces condensation of any water vapour present in the air. Clouds can only form when there are dust particles to act as nuclei for the water droplets that compose them. That is the reason that fogs and mists are often associated with large cities. In summer the air over a large town becomes hotter than the air over the surrounding countryside because the pavements and buildings radiate back more of the sun's heat. This means the development of a local system of lower pressure and winds, light as a rule, tend to blow in from the country. This may account for the fact that large towns seem to have a greater incidence of thunderstorms than country districts do.

This effect of producing local systems of low pressure was illustrated to a greater extent during the saturation raids, with fire-bombs, on German cities during the war, when the terrific heat generated by the great fires started caused a violent uprush of hot air at low pressures and the result was a terrific inrush of air from outside. This strong wind that developed caused great damage to buildings already weakened by the fires, which were, in turn, fanned into greater intensity.

In connection with atmospheric conditions changed by man it may be worth referring to some popular illusions, namely the beliefs some people hold that bad weather is caused by radio or by heavy shelling. Although it is true that a shell fired into a cloud may cause precipitation by upsetting the temperature and pressure conditions locally, there is no proof at all that shelling affects the weather conditions, especially of places some distance away, to any perceptible extent. It should be borne in mind that the effects of shelling although disastrous locally are infinitesimal in comparison with the forces involved in the production of weather. The gravitational attraction of the moon which exerts so marked an effect on the waters of the world, only produces a "tide" in the atmosphere whose pressure is so slight that no ordinary barometer could register it. Much less, therefore, would be the effect from gun-fire, even if sustained and heavy.

CHAPTER XIII

THE SUN—MOTHER EARTH'S PARENT

According to the Nebular Hypothesis, the sun may be regarded as the partially condensed central major portion of the nebula from which the Solar System has segregated out, whilst on the "Accident Hypothesis" it was formerly a much larger star from which the material that now forms the planets has been torn. In either case we may regard the sun as the parent of Mother Earth. The sun is a star and is unique in being the only star that appears as anything more than a point of light in the most powerful telescopes yet constructed, thus it is possible to make a detailed study of its surface.

Many ancient and primitive peoples have worshipped the sun as a deity, and this is not surprising in view of the fact that on the light and heat emitted by it and received on the earth, all terrestrial life depends. Not only does life depend on the radiant energy of the sun but all the forms of energy used and harnessed by man come ultimately from the same source. Coal and petroleum are both of organic origin, that is they are formed from the remains of plants and animals, and these were dependent on the sun. Water-power and wind-power are also indirectly of solar origin, for it is the varying distribution of solar heat over the surface of the earth that causes both the evaporation of water from the seas and also produces the pressure differences that result in the winds which bear the water vapour in the form of clouds from which it is precipitated in the form of rain and snow so giving rise to streams. Direct use has also been made of solar radiation as a source of power by utilizing the heat rays which are concentrated and transformed into other usable forms of energy. Human energy is derived from the food eaten, and this comes from plants and animals whose life is the result of the sun.

Solar Temperature

Some solar dimensions have already been given in the first chapter, but a few more figures are appended before we pass to more descriptive matter. The sun is situated some 40 million light-years from the centre of our Galaxy and together with its attendant plants partakes of the general movement of the stars around that centre, and moves in its orbit at a velocity of approximately 190 miles per second. The surface temperature is 6,000–7,000°C. (approximately 12,000°F.), which is almost twice the highest temperature artificially obtainable on earth, the temperature of the electric arc, 4,000°C., whilst the internal temperature must be in the order of 20 millions of degrees. The energy

being radiated from every square foot of the sun's surface is 15,000 h.p., and the light given out is equal to the light of $1,575 \times 10^{27}$ standard candles. Of this colossal outpouring of energy and light only an infinitesimal proportion is intercepted by the planets, the greater part of it is radiated away into space and becomes dissipated.

The sun is an incandescent globe of gases, approximately spherical in shape. At the high temperatures existing on the sun matter exists in the form of elements and free electrons; all compounds would break up. Many of the elements exist in forms different from those in which they exist on earth and this formerly gave rise to the idea that there were elements in the sun that did not occur on earth because there were, in the solar spectra, lines then unidentified but which are now known to be caused by normal elements existing under conditions of very high temperature and very low pressure. Actually, the sun is composed of similar elements as those of earth, 60 of the 92 known elements have been identified and these include hydrogen, oxygen, nitrogen, carbon, sodium, calcium and iron.

H. N. Russell has estimated the abundance of elements in the sun's outer layer as one half hydrogen, one quarter oxygen, and metals in the following relative order, magnesium, iron, sodium and silicon for most of the remainder. Certain elements that have not yet been identified in the sun may be present at deeper levels in it. It is only the surface and atmosphere that are open to spectroscopic analysis.

The Structure of the Sun

Like the earth, and in fact any body that has condensed and cooled from a gaseous or molten condition, and in which, therefore, segregation of materials can occur, the sun is made up of various shells or layers. In addition to the internal shells of which little is known, except by inference, there are three shells that are identified and named, namely, the photosphere, chromosphere and corona. The photosphere, which, as its name implies, is the light-emitting layer, is the visible surface of the sun and is seen as a sheet of clouds which float in a less visible atmosphere, hence the sun presents a mottled appearance when it is photographed through a filter which allows only light of one wave-length to pass.

The chromosphere is a coloured outer layer of gases, mainly hydrogen, helium and calcium, forming a solar atmosphere some 5,000 miles in depth.

The corona, which is only visible in total eclipses, appears as a halo of pearly-white colour. It consists of irregular and faintly luminous clouds and extends outwards from the sun irregularly for several millions of miles, with the brightness of the full moon. The corona is seen as a fairly uniform cloud when sun-spots (see below) are at their maximum, but

when sun-spots are at a minimum it contains fine plumes and streamers. Corona spectra exhibit lines which were not satisfactorily identified until recently when similar lines were found in the spectra of exploding stars, or *novæ*. This means that we are dealing with matter at very high temperatures and very low pressures. Edlén, a Swedish scientist, has recently identified these lines with iron, nickel, calcium and argon in a state of ionization, that is with some of the orbital electrons removed from the atoms.

Sun-spots

Four hundred years ago when Galileo turned his improved—yet still small—telescopes to the sun he noticed that the surface was not flawless as contemporary thought, based on Aristotle's ideas, held it to be. He noticed dark patches which changed in number and size and position. From the motion of these spots Galileo inferred that the sun rotated on an axis. This has since been confirmed by better observations and by photographic investigation, and a remarkable fact emerges, namely, that all portions of the sun do not rotate at the same rate. At the solar Equator a complete rotation is made every 25·32 days, at latitude 40° rotation takes place in 27·2 days, whilst in the polar regions it takes 35 days. This differential speed of rotation obviously indicates that the sun is in a very fluid state. Rotation would of course be expected on either the Nebular or Accident Hypotheses.

Much still remains to be learned about sun-spots but there are some facts available. They suddenly appear as dark areas lasting anything from a few weeks to several months, apparently passing across the sun's surface as a consequence of its rotation. They vary in size, and may be anything from 500 to 50,000 miles across. They show a vortex motion inside them and they are, apparently, gigantic storms of flaming hydrogen, formed by the sudden expansion of solar gases rising to the sun's surface. It is this sudden expansion resulting in a temporary drop in temperature of, maybe, 2,000°C. which causes the darker patch seen as the spot. Hydrogen from the corona is sucked down into the vortex and burnt.

Although at first sight the sun-spots appear haphazardly, careful observation shows that there is a regular but as yet unexplained cycle of activity, a maximum being reached every 11·2 years, and this maximum coincides with the maximum of magnetic storms and auroræ, for there is a connection between these phenomena. There also appears to be a variation of the sun's radiation coinciding with the number of sun-spots. It has been noticed that if spots are numerous and the polar snow-cap of Mars is turned towards the sun, then the cap decreases in size. Some observers have reported an increase in the solar heat received on the earth at maximum sun-spot activity, but not all scientists are agreed on

this matter yet. Variations in the light reflected by Jupiter is also associated with sun-spot activity. Ultra-violet radiation from the sun is increased by 100–150% at sun-spot maxima, and it is this increase in short-wave radiation which produced the magnetic storms and affects the ionosphere and, hence, radio.

The appearance of large sun-spots, together with several smaller groups, noted in late 1944, probably indicates a rise in solar activity towards the next maximum which is due. It was noted that in December 1944 there was much disturbance in the earth's magnetic field and considerable interference with long-distance radio. Similar effects were observed to a more marked degree between January 29 and February 12, 1946.

Solar Energy

What is the source of the energy that is constantly being poured out from the sun? It is not from combustion in the ordinary sense, which is the rapid oxydation of matter, for as already noted chemical compounds do not exist in the sun. No, the energy of the sun is atomic energy—that source of power so much written about and sought after on earth. The internal temperature of the sun is enormous, probably 20,000,000°C. At the centre, the internal pressure must also be very great, something of the order of 50,000 pounds per square inch. Under such conditions atoms of matter would be stripped of their outer orbital electrons. This would mean that the atoms resulting could then be much more closely packed than normal atoms could be, and the matter in the centre would thus have a very high density whilst still remaining a gas. In this atom stripping, or disintegration—something analogous to what is happening in the breakdown of the radioactive elements on earth—energy would be released and it is here that the source of the energy radiated by the sun is to be sought.

Some idea of the terrific energy shut up within the atom may be gained from the new "atomic bomb", which, although only one half-ton in weight—and much of that would be the containing material only—has the explosive force of 2,000 of the 10-ton bombs used with such devastating effect by the Royal Air Force.

As it pours out radiation, the sun is losing mass, for there is a conversion of matter into radiant energy, and that loss is about 300,000 million tons per day, but so great is the mass of the sun that it can continue to lose weight at that rate for a very long time yet. There is another consequence of the loss of weight which affects the earth, for reduction in the mass of the sun means a lessening in its gravitational attraction, and as a matter of fact, the earth is getting farther from the sun by a rate of a yard a century, therefore in a billion years it will be one-tenth farther away than it is today (about 9·3 million miles more

distant). The earth receives less radiation the farther away it gets; after a billion years it would receive only four-fifths of its present amount of radiation, and the mean temperature of the earth's surface would be 15°C. lower. This is on the assumption that the sun's radiation were maintained at the present rate, but since the sun is losing mass, it will send out less radiaton, so that after a billion years the total fall in mean temperature at the earth's surface would be 30°C.

CHAPTER XIV

THE MOON—MOTHER EARTH'S ONLY DAUGHTER

OUR nearest neighbour in space and, probably, once a part of the earth, the moon is a familiar object to all, and one that has been studied for long. A more or less spherical body, she revolves around the earth once in 27 days 7 hours at a distance varying from 221,800 miles to 252,600 miles (mean distance, 238,800), and since she rotates on her own axis in the same time as she revolves around the earth, she always presents approximately the same part of her surface to us. Owing to the libration in longitude and latitude she presents to us, at varying times, 59% of her surface. (See Glossary.)

The moon is only one-three-hundred-and-seventieth the distance of the sun away. It would take 81 moons to balance the earth, could those bodies be placed in the scales of some colossal balance, whilst in volume she is but one-forty-ninth that of the earth. It is her nearness that makes her appear so large an object in the sky.

The diameter of the moon is approximately 2,160 miles, or roughly two-thirds of the distance between New York and Liverpool. Since some of the mountains that can be seen on her surface rise to heights of 20,000 feet and more, she has relatively deeper wrinkles on her face than has her mother, the earth, whose highest mountain is but 29,000 feet high, but whose girth is nearly four times that of the moon. Someone may be thinking, "How can we know the height of the mountains of the moon?" That is learned by measuring the length of shadows that they cast, for the moon is not self-luminous, but is lit by and reflects the light of the sun. This greater wrinkling of the moon's surface may be due, in part, to the absence of certain types of sub-aerial denudation such as rain action and, in part, to the non-existence of isostatic compensation, for the moon's internal structure is probably very different from that of the earth. Since she is so much smaller the moon exerts a much smaller gravitational attraction and that, too, would play some part in permitting the existence of abnormally high mountains.

Bright though the light afforded by the full moon is, it is but feeble compared with that of the sun; it would require 618,000 full moons in the sky to give the same amount and intensity of light as does the June sun, at noon-day. This figure is, of course, an average, as the distance of the moon from earth varies considerably as noted above. Yet, on the other hand, the light of the full moon is more than 10 times as bright as the combined light of all the stars on the clearest night.

The Lunar Surface

Everyone, including the smallest child, is familiar with the "man in the moon", those shadowy patches on her surface, which seem to make a

picture. Some, at least, know that those markings seen are due to irregularities on the surface of the moon, causing shadows. So near in space, and so easy to observe is the moon, that her surface (at least of that side she ever presents to us) is almost as well known in its main features, as is the face of the earth. Maps have been made of the hills and craters that are dotted on the surface, the heights of most of the principal mountains are known with fair accuracy.

A weird world it is that the telescope reveals, a dead world, for there is no atmosphere upon the moon, so that life as we understand it could not exist there. No air to act as a blanket for the surface, means that days are intensely hot, for the sun's rays strike directly on the bare rocks, whilst nights are bitterly cold, for no sooner are the warming rays withdrawn from the surface than radiation, unhindered by an atmosphere, reduces the rocks to the temperature of space, or almost so. Such a big alternation of temperature every day results in the breaking up of the rocks, as a consequence of the rapid change in volume, expansion and contraction. Changes in the topography of the moon's surface are therefore seen from time to time. Extinct volcanoes, some with huge craters whose walls are still very high, help to make the scenery of the moon still more bizarre. The largest crater is 150 miles across. Perhaps the grandest of them is that named after the famous astonomer, Copernicus; this is 56 miles across, with a level floor from which rise several peaks reaching heights of 2,000 feet. The crater is surrounded by a ring 12,000 feet high, broken in places into terraces; the slope in places is at an angle of 60°.

The volcanoes that once were active there must have been large ones, indeed, to have formed such huge craters as those named above, whilst many others are much larger than any on earth. No volcanic activity can be observed today, for the moon is cold and dead; being so much smaller, and having no atmosphere, she has cooled much more quickly than the earth, which is still intensely hot inside the thin, solid crust. Perhaps it would be untrue to say that the moon is absolutely cold, for some astonomers claim that patches of whitish colour can be seen from time to time around the craters, and they think it likely that these are deposits of mineral matter formed by the solidification of gaseous matter emitted from cracks and fissures, somewhat after the same manner in which sulphur is deposited around volcanoes on the earth. If their surmise is true then it may well be that the moon's interior is still at a relatively high temperature. But there is nothing definitely known about this phenomenon and it may be, as the majority of astonomers hold, that the effects are due to the varying angles at which the rays from the sun strike the moon's surface.

Since there is no trace of an atmosphere, on the moon, there is no water there, either; no streams, no rain to smooth and round off the angular and jagged scenery, to make lakes of the craters, or lead to the establishment of some lowly forms of life. Another consequence of the

absence of air is that an imaginary observer on the moon would see no phenomena of twilight; the sun would suddenly appear, or disappear, over the horizon. One minute it would be freezingly cold, the next the sun would appear in full brightness and heat-giving powers. Still another odd effect would be that if any water could be taken to the moon, it would immediately vaporize in the daytime, because there would be no atmospheric pressure to prevent it from "boiling" at a low temperature. So that any earth-born traveller who ever reached the moon on some fantastic rocket would not be able to make a cup of tea or boil an egg—he could fry one, though, upon the sun-lit and sun-heated rocks, so high a temperature would they reach.

There can be no soil, since there is no moisture, no worms or any living creatures, or plants; just a bare rock surface, with poles of scree at the foot of every crumbling cliff or slope, for every slope would be disintegrating owing to the alternation of heat and cold, each day. A geologist would have no sedimentary rocks to study, for there are none, but he would be able to revel—could he stand the high day temperatures and live without air—in the igneous rocks that everywhere form the surface, and the unexampled evidence of volcanic activity.

Not only craters but mountain ranges help to diversify the surface, some, for example that which is named the Apennines, run for many hundreds of miles. Deep, steep-sided valleys cut their flanks, valleys that have never known a stream, and were, doubtless, formed by earthquakes; for crustal movements on a large scale must have taken place in those far-off days when the moon was hotter than it is today. Such crustal movements once occurred on the earth, but erosion and deposition since have helped to heal and cover the ancient scars, and only in the record of the rocks can we learn of them, not by direct observation as in the case of the moon.

One other feature of the lunar scenery deserves mention for it can be seen by the naked eye. There are a number of grey spots visible; these were called "seas" by the observers and the name is still used in its Latin form of "*mare*", although we now know that they are not really such, but are large plains covered with some dark material.

It may be of interest to list a few of the more prominent features of the moon, which can be seen with the naked eye. We have already mentioned the mountain range 460 miles long called the Apennines, the highest summit of which, Huyghens, is 18,000 feet high—this means that the moon is much more deeply wrinkled than the earth. The brightest object on the moon's surface is to be seen in the north-east quadrant, it is the crater Aristarchus, which is visible as a bright circle. Towards the southern limb there is another bright object, the crater Tycho, which is 54 miles in diameter and over 16,000 feet deep; bright rays appear to radiate from it. The two chief "seas" are Mare Crisium and Mare Serentatis; the former appears as a dark grey oval plain near the west-north-west limb of the moon, it is 280 miles long from north to south

and 354 miles across; the latter is nearly circular, and is 428 miles across and lies just to the north of the centre. It contains a crater.

The Composition of the Moon

Since the moon is cold and only shines by the reflected light of the sun, it is impossible for us to learn by spectroscopic investigation of what elements it is composed, as can be done in the case of the self-luminous stars. So we should know little about the constitution of the moon were it not for the fact that astronomers believe that the moon once formed part of the earth. If that belief is true then it follows that the rocks of the moon are akin in their constitution to those of the crust of the earth. The density of the moon is just over one-half that of the earth as a whole, or about that of the upper layers of the crust, which is what would be expected if the material forming the moon was once part of the earth, for it would be the surface matter that would be separated off. In considering the nature of the moon's component material, especially the surface, allowances must be made for the fact that there is neither atmosphere nor water on the satellite, so that the ordinary agents of sub-aerial denudation that produce mineralogical changes in terrestrial rocks do not operate on the moon. There would be no alteration of rocks by hydrous action, as for example, the weathering of granite into kaolin, or china-clay. There would also be no deposition in water and no stratified sediments, a state of affairs which is not easy for us to visualize, for even in arid areas where there are no streams or seas in which deposits can accumulate, there is an atmosphere and there are winds which carry material that is subsequently deposited in irregularly stratified masses. But since there is no atmosphere on the moon, there can be no winds. The only deposits would be screes formed at the base of cliffs and steep slopes as a result of the accumulation of fragmentary material falling from the heights above. And all the fragments would be rough and angular.

The Origin of the Moon

But what is it that makes us think that the moon was once part of the earth? There are two main reasons: firstly, the fact that the moon revolves around the earth at no great distance away from it, astronomically speaking. This would seem to suggest that there is an intimate connection between the two, and from analogy with the earth and sun relationship, it would seem justifiable to assume that the moon was formed from the earth, that the matter forming it was drawn off, or thrown off by the earth, when still molten on the surface. No reputable

scientist would, perhaps, teach today as was taught by some in the past, that the depression on the earth's surface, which, filled with water, forms the Pacific Ocean, represents the hole that was made when the moon was torn away. But there can be little doubt that "fair Luna's orb" is a daughter, and the only one, of Mother Earth.

The second reason is this. The moon's gravitational pull is one of the main factors in producing tides on the earth. Every particle of matter on the earth is attracted by the moon, but those which are on the side of the earth nearest to it are attracted most, therefore there is a tendency for such particles as can easily move to pile up on that side. Water is the most mobile matter on the earth, therefore a wave of water tends to pile up, that is, a tide is produced. Now it has been learned that the friction which the tides exert on the solid surface of the earth is sufficient to slow down the speed of rotation of the earth and that rate of retardation can be, and has been, measured. It is sufficient to lengthen the day at the rate of one second in each 120,000 years ago. Thus the earth rotated on its own axis in 21 hours 40 minutes a thousand million years ago, that is on the assumption that the loss of speed has been uniform. The moon is slowly retreating from the earth and must, at that distant time, have been very close to the earth.

The conclusion seems justified on the above grounds, of assuming that the matter which formed the moon separated off from the earth when the latter body was young, and its surface had not begun to cool sufficiently to form a solid crust. The force may well have been the centrifugal force resulting from the much faster rotation of the earth at that time in its history. Huge waves would have been produced in the molten matter, and, at length, one of these "broke" and the resultant "spray" became the moon.

The moon is responsible for the eclipses of the sun that occur from time to time. She revolves around the earth in an orbit which is slightly inclined to the plane in which the earth revolves around the sun, so that it cuts the latter at two points. When a new moon occurs near either of these points of intersection, there is an eclipse of the sun, for then sun, moon and earth are in one straight line, with the moon in the centre cutting out the sun. Since the moon is so small no total eclipse of the sun is seen all over the earth but only in a limited area. At full moon (that is when the moon is on the side of the earth opposite the sun) total eclipse of the moon occurs if it enters the shadow which the earth makes in space. This occurs when sun, earth and moon are in a straight line, that is when full moon takes place near a point of intersection of the orbits of the moon and earth.

A popular belief about the moon may be referred to here, viz. that there is some connection between our satellite and our weather. Observations carried on over long periods show that there is no such connection. It might be supposed that there was some truth in the old idea, since it is well known that the moon plays a great part in the phenomena of the

ocean tides. As a matter of fact there are tides produced in the atmosphere, as in the seas, but they represent a difference of less than one-thousandth of an inch in barometric pressure and have therefore no appreciable effect on our weather. It may be of interest to quote some lines from *The Weather*, by George Kimble and Raymond Bush:

> The moon and the weather
> May change together;
> But change of the moon
> Does not change the weather.
> If we'd no moon at all
> (And that may seem strange)
> We still should have weather
> That's subject to change.

CHAPTER XV

BROTHERS AND SISTERS OF THE EARTH

THE earth is, as already stated, a child of the sun and a member of the Solar System. For the sake of completeness a little must now be stated about the remainder of the family. This is divided into three groups: there are the other planets—details have already been given of dimensions, etc., in Chapter I—the meteors and the comets. The whole family forms a unit with the sun at the centre. That body alone would be visible as a star from the next nearest object in space, the star Proxima Centauri, which is 4⅓ light years away.

The Planets

Mercury—the nearest planet to the sun—is very difficult to observe, and there is, therefore, still much uncertainty about it. It is quite a small brother of the earth, having a mass only one-thirty-second that of our planet. Mercury's surface must be intensely hot; it is estimated that the intensity of solar radiation at its mid-winter is more than four times that received at any time or place on earth, whilst in midsummer it would be nine times as great. Not only that, but the changes in temperature must take place very rapidly as the Mercury year (i.e. its time of revolution round the sun) is only 88 days. Another peculiarity is that apparently the small planet rotates on its axis in the same period, so that it always presents the same face towards the sun, i.e. one hemisphere enjoys perpetual day and the other perpetual night. Due to the fact that the velocity with which Mercury travels round the sun is very variable, whilst the speed of rotation is uniform, rather more than half the surface is presented to the sun during a year. It is practically certain that Mercury has no atmosphere. In view of this fact, and of the great temperature variations that exist upon that planet, it is scarcely likely that any life —at any rate, as we know it—can subsist there.

Moving outwards from the sun, the next relative of the earth to which we come is her sister Venus, the brightest "star" in the night sky. She is often visible as the so-called morning or evening star Her size is about that of the earth. Venus has a very thick atmosphere with masses of heavy cloud in it. These must shield the planet's surface to some extent from the sun's rays, which owing to her relative nearness to that body would otherwise be very hot. Another consequence is that the actual surface of the planet cannot be seen. There is some reason to suppose that the planet is entirely surrounded by water-vapour. There is little likelihood of any life existing there. Venus is remarkable for

another feature, her orbit very closely approximates to a circle; there is less than 1% difference between her greatest and least distances from the sun.

The earth lies between Venus and Mars, whose surface is best known of all the heavenly bodies with the sole exception of the moon, although since Mars is about 140 times as far away as the moon (even when it is nearest to the earth) the knowledge that we have of it is not very detailed. Mars is quite a little brother, its diameter being little more than half that of the earth. It rotates on its axis in a period only half an hour longer than our day, so that the aspect it presents to us changes. There is an atmosphere with thin clouds floating in it. As it is more distant from the sun than is the earth, the temperature of its surface falls lower than does that of the earth; it falls below freezing-point every night, even on the Martian equator. This nightly fall in temperature is increased by the rarity of the atmosphere and absence of cloud blanket to retard radiation of the surface heat. Large white caps cover the polar regions of Mars during its winters, these are ice- or snow-caps, and the rate at which they melt in the Martian summers can be measured.

The amount of heat falling on the planet from the sun can be calculated so that it is possible to estimate the thickness of the snow-caps, and the results show that they are but a few inches thick. This is an indication of the aridity of the planet, which is further borne out by the fact that there are no oceans visible on it. The surface appears to be mainly barren deserts of a reddish colour, and this accounts for the characteristic red colour of the planet, hence the reason probably why it is named after Mars, the god of war. There are some darker patches amid the red, and these increase in size during the Martian summers and are, therefore, considered to be patches of vegetation.

The fact that oxygen is known to be one of the constituent gases of the atmosphere there, together with the presence of some water, indicates the possibility of life existing on the planet. Mars is, in fact, almost the only other possible place in the Solar System where anything like life as we understand it could exist, although any forms that live there would in all probability be very different from any on earth. Mars is much colder than the earth and has therefore an interest for us in showing us what the earth may look like in the far-distant future. It is the planet most like our earth in most respects, above all in its size and in the possession of an atmosphere which can be seen through and so can reveal something of its surface.

No mention of this planet would be complete without a reference to the fine, dark, straight lines which were noted by Schiaperelli in 1877, and named by him "canali". This word has been rather badly translated into English as "canals". They were once supposed to indicate the presence on Mars of beings analogous to men, by whom they were presumably constructed for irrigation purposes. English astronomers on the whole do not accept this view, which was strongly advocated by Professor

Lowell. It is now generally accepted that the subjective tendency of the eye to connect up detail in the form of irregular shadings has been responsible for the false views of the surface of Mars. Dr. Barnard and M. Antoniadi, and others, using much more powerful telescopes, have not confirmed the view that the "canals" form a clearly defined geometrical pattern.

One other feature is worthy of mention here. Mars has two very small satellites; Deimos, the outer one, revolves around its parent planet in a period of just over 30 hours. Phobos, the inner one, is the more interesting, as it revolves around Mars in the extraordinarily short time of 7 hours 38 minutes and 14 seconds, that is, it completes three revolutions in a Martian day. To add to the odd effect thus visible in the Martian sky, the two moons appear to revolve in opposite directions around the planet.

Between Mars and the next planet outwards from the sun there is a swarm of minor planets, or Asteroids, the largest of which is only a few hundred miles in diameter. They are invisible to the naked eye, and were difficult to detect even with telescopes until recently. It was not until the first day of the last century that the Italian astronomer, Piazzi, discovered the first of them, Ceres as it is called. It had previously been surmised that there might be another planet between Mars and Jupiter from a consideration of what is known as Bode's Law. This interesting formula, for which there is no explanation, gives the relative distances of the planets from the sun with considerable accuracy. It was arrived at in this way: take the series of numbers, 0, 3, 6, 12, 24, 48, 96, to each of these add four, thus obtaining another series, 4, 7, 10, 16, 28, 52, 100. With the exception of 28 the other members of the series approximate to the relative distances of the planets from the sun; these are Mercury 3·9, Venus 7·2, Earth 10, Mars 15·2, Jupiter 52·9 and Saturn 95·4. It was deemed probable, therefore, that there might be another planet corresponding to 28. This set astronomers seeking, with the result that the Asteroids were discovered, and nearly 2,000 of them have now been noted. Ceres is the largest with a diameter of 485 miles, the others are quite small. The suggestion has been put forward that they represent the remains of a larger disrupted planet.

Jupiter, to which we now come in our journey outwards from the sun, is the largest of the family, it has a volume 1,000 times greater than that of the earth. Probably it is not in a solid state. Through a telescope the face of the planet appears to be covered with belts of changing colour—probably clouds—which lie parallel to its Equator. In 1924, Dr. Harold Jeffreys, by means of a mathematical analysis, came to the conclusion that Jupiter probably had a central rocky core which was surrounded by a thick shell of ice several thousand miles in thickness, with a deep atmosphere outside it. This suggestion has not been definitely confirmed, but is interesting as it is diametrically opposite to the older view that Jupiter was an intensely hot planet that had not yet solidified.

In either case, there is little probability that life could exist on the planet. Jupiter is interesting in that it possesses no less than 11 satellites, or moons, the largest of which is about the same size as is our moon.

Some 886 million miles out from the sun lies the unique planet Saturn, the most distant planet known to the ancients who had no telescopic aid to vision. It is unique in possessing a broad, flat equatorial girdle, or belt. This really consists of three concentric "rings", or circular discs; the two outer sections are bright, the inmost one is darker and semi-transparent. In a large telescope the separation of the rings can be seen. The inner ring begins about 7,000 miles out from the surface of Saturn, whilst the outer edge of the outer ring is about 48,000 miles from the surface. The rings are only about 10 miles in thickness and are not visible in side view. They consist of an enormous number of small meteoric particles—tiny satellites—all revolving around Saturn, and they may have originated from the break-up of a former single satellite which approached very close to the parent planet and which disintegrated under its strong gravitational attraction.

Saturn, which has a very low density probably due to the fact that the greater portion of what we see of it is atmosphere, has another satellite, Titan. This moon is interesting as spectrographic analysis of it made in 1944 shows that its atmosphere, like that of Saturn, contains methane and ammonia. It has an extremely low temperature, something of the order of $-160°C.$, so that almost everything would be frozen to its surface. It is very distant from the sun, from which it would receive only 1% of the heat received from the same source by our moon.

The remaining planets—Uranus, Neptune and Pluto, in order outwards from Saturn—were not discovered until the advent of good telescopes. Uranus was the first to be observed by the great eighteenth-century astronomer, Sir William Herschel, in 1781. Uranus is so far distant from the sun that it takes 84 of our years to make one complete circuit of its orbit. It is so distant that our knowledge of it is still very limited; it has a diameter about four times that of the earth but is only 15 times as heavy, that is it is less dense than the earth which may be due to its being covered with a thick atmosphere. It rotates—as do all the planets—on its axis in a period of about 11 hours. It is known to possess four satellites; the nearest one revolves around its parent every two and a half days, the most distant every 13½ days.

Still less is known about Neptune, which, like Uranus, is about 30,000 miles in diameter and has a low density. The existence of this planet had been suggested as a result of mathematical reasoning by Le Verrier and J. C. Adams, who studied the perturbations in the motion of Uranus and could only explain them on the basis of the existence of another and more distant planet whose gravitational attraction produced the effects noted. The planet was not observed until the year 1846 by Galle, in Berlin. Neptune is 2,800 million miles away from the sun, and it takes 165 years to complete its orbit, that is, it has not made one

complete circuit since it was first seen by man. Like our earth, this distant member of the solar family has, so far as is known, only one satellite.

In 1930 there came the discovery of a yet more distant planet by Tombaugh, from the Flagstaff Observatory, in Arizona. This newly-found child of the sun was, in accordance with ancient precedent, named after a mythological deity, Pluto. It revolves around the sun in the period of 248 years at a mean distance from it of 3,675 million miles. Beyond these facts and the further one that Pluto's orbit is very eccentric, little is as yet known about the new discovery.

Comets and Meteors

To complete this chapter a short account must now be given of two other groups of heavenly bodies which belong to the Solar System, namely, the comets and meteors. These may be termed the erratic sisters of Mother Earth, for they do not move in the same regular orbits as the planets do, yet nevertheless they do move in definable and calculable orbits which are very elongated ellipses. The result is that they appear to cut through the planetary paths at regular intervals. The nature of comets is no longer mysterious. These bodies, whose appearance was once the cause of considerable consternation amongst men, and which were deemed to forebode dire events, move as already indicated in very elongated ellipses, swinging near the sun at one time and then moving far away often maybe beyond the boundaries of the Solar System (as defined by planetary orbits). Many of the cometary orbits have been calculated and the reappearance of numerous identified comets can be predicted.

A comet consists of three parts. There is the head, or nucleus, which is a loose agglomeration of particles which vary in size, the great majority being quite small but some being of the order of several tons weight, and which are held together by the gravitational attraction of the whole mass. The head has a diameter of many thousands of miles. The heat of the sun causes the particles composing the head to exude gases which stream away from the head and become luminous forming the *coma* of the comet. As the gases recede far from the nucleus and become extremely rarified, the molecules probably carry off some fine dust particles from the nucleus, and the luminous tail appears. The tail points away from the sun owing to the effect of light repulsion on the very minute particles found in it. The tail of a comet may be several million miles in length. The mass of a comet is very small; the earth is millions of times heavier than the largest known comet.

In general, therefore, it may be said that the effect of a comet hitting the earth would be a splendid display of shooting stars, with some of the larger masses reaching the earth's surface as solid bodies, but with none of the world-shaking effects pictured by sensational fiction writers. Such

collisions actually occurred in 1833 and 1866, when the earth passed through the debris of Tempel's Comet, without many people being any the wiser. Some of the best-known periodic comets are Halley's Comet, first discovered by the Chinese in the year 240 B.C., which returns approximately every 76 years, the last occasion being in 1910; Encke's Comet, which returns every three and a third years, the shortest period known; and Donati's Comet, seen in 1858, and which will not return for another 2,000 years.

Comets are not stable entities, they often break up into clouds of meteoric particles which still go on moving in the same orbits as the original comets did. This is shown by the fact that the expected reappearance of a comet does not take place, but instead there is a display of "shooting stars", or meteors. To a consideration of these we now pass. Meteors—or as they are popularly called, "shooting stars"—are masses of matter, usually quite small, consisting of known elements, often nickel-iron, moving in orbits around the sun, which trace out very elongated ellipses, although some have orbits approaching the form of those of the minor planets. At the distance of the earth from the sun the speed of one of these meteors, in its orbit, is 26 miles per second, and as the speed of the earth in its orbital motion is about 18½ miles per second, the velocity with which a meteor approaches the earth may vary from 7½ to over 44 miles per second, according to whether the meteor overtakes or meets the earth. The gravitational attraction of the earth increases the speed of the slower meteors by 2½ miles per second, but has little effect on the faster ones.

There are, therefore, no meteors that encounter the earth with speeds less than 10 miles per second. As the meteors fall through the atmosphere they become heated due to friction with the molecules of atmospheric gasses and usually they are entirely burnt out, or consumed, before they reach the surface. Occasionally, however, a portion of a large one does reach the earth's surface, it is then known as a meteorite. Analysis of meteorites shows us that the main constituent is nickel-iron. There is in the Natural History Museum at South Kensington a stone of 56 pounds weight, that was seen to fall in Yorkshire in 1795. On April 20, 1876, an angular mass of iron fell at Rowton, in Shropshire, to the accompaniment of a rumbling noise and a startling explosion. This meteorite weighed 7¾ pounds, and is also preserved at South Kensington.

But these British examples are mere infants when compared with the Baculierito Meteorite, in Mexico, which is 50 tons weight, or another of 36½ tons which Commander Peary transported to New York. It is not the attraction of the earth that causes the collisions between our planet and the meteors, though the earth's attraction does slightly increase the number of meteors that strike the atmosphere. The impact of meteors is slightly and slowly increasing the mass of the earth; it has been estimated that some 12,000 tons of meteoritic material is added to it each year. Thus the earth acts like a gigantic vacuum-cleaner, slowly cleaning

up the smaller masses of matter in those parts of inter-planetary space through which it passes in its annual journey around the sun.

There are periods of the year during which meteoric displays are more common than at others. This is due to the fact that at such times the earth is passing through the orbit of a meteoric swarm, which is often the debris of a comet. There were formerly fine displays to be seen about November 12–14; these were called the Leonids, because they appeared to radiate from the position of the constellation Leo. (This method of naming meteor showers after their apparent point of origin is the usual one.) The Leonids have been less brilliant of later years. They were caused when the earth passed through the debris of Tempel's Comet, which has now almost vanished. Another display, the Andromids, seen about November 17–23, is also becoming rather feeble. This shower, or swarm, was shown to be moving along the same orbit as the comet Biela, which, dividing in 1846, has not been seen since 1852. The period of the Andromids is six and a half years, that of the Leonids is 33 to 34 years. This means that the latter have a larger orbit. There are about nine well-known and regular showers that are associated with the debris of former comets, the orbits of which intersect that of the earth.

In addition to those already mentioned there are the Aqurid meteors, which are seen in early May and represent the debris of Halley's Comet, as may also the Orionids which are seen about October 18–26. Halley's Comet is interesting in that it had a retrograde movement, that is it moved around the sun in a direction opposite to that of the earth, therefore when the earth encounters its debris the particles strike the atmosphere at high speeds, 10 to 45 miles per second, this means that they are volatilized quickly. "Shooting stars" from this display would burn out very rapidly and only appear to pursue short courses in the night sky. The Perseid Shower, which reaches its maximum about August 10–12, represents the debris of Tuttle's Comet, and the Lyrid Shower of April 18–22 that of Thatcher's Comet.

Hundreds of millions of meteors strike the earth's atmosphere every year, but very few of them are large enough to pass through it without being burnt up—that is why "shooting stars" appear to vanish in mid-air. But the weight of those that are burnt up is added to that of the earth, and the other planets are similarly acquiring matter, too, so that inter-planetary space is gradually being "cleaned-up".

CHAPTER XVI

PRACTICALITIES

In the preceding chapters some account has been given of the knowledge of the earth, but the question may well be asked how do we obtain the necessary data on which to base our ideas and theories. It is a fact that until comparatively recently only the outer skin of the earth could be directly observed, that very limited shell that lay between the bottom of the deepest mine and the top of the highest mountain climbed by men. But gradually man has been able to extend the thickness of that shell, borings have been made to greater depths with the advance of technology. High-flying aeroplanes and balloons have enabled men to explore still higher altitudes in the atmosphere, and the invention of new types of recording instruments have enabled them to apply the new knowledge of physics to explore the interior of the earth. A brief account of some of the new methods is given below, but first of all a short account is given of how we learn of the upper crust by geological mapping.

Geological Mapping

The various sedimentary rock-beds, or strata, which form the upper crust were originally laid down horizontally under water—at least for the most part. But except in a few areas they have since been bent, or folded, or fractured, so that now they lie at varying angles. Newer rocks have been eroded away thus exposing older ones, older ones have been folded or thrust over newer ones, and the result is often very complicated.

As already stated, rocks can be identified by their nature and their fossil content so that it is possible for the geologist in the field to map the outcrops of various beds on the surface. He also measures their angles of slope, or dip, and the direction in which the strata are dipping. These particulars are entered in the appropriate positions on large-scale maps. As many exposures of the rocks as possible are examined and recorded, it is fairly easy, in some districts, to obtain a fair number of exposures; in others, especially where the land is wooded, well-cultivated, or rather level, it is not so easy, and indirect methods have to be used. For example, if a limestone lies immediately above a clay there will be tendency for springs to occur along the line of junction, so that the presence of such will give a fair indication of the boundary even when the actual rocks are obscured.

Other ways of learning what rocks lie beneath the soil covering are

the inspection of pebbles, etc., thrown out by rabbits from their burrows, the examination of stream beds (although allowance has to be made here for the fact that streams carry material downwards from the actual point of origin), records made of any well-sinking or drainage operations, the shape of hills and slopes—sudden changes in slope usually indicate a change in the nature of the rock. After all the possible information has been collected in the field there begins the task of piecing the information together and making as complete a picture as possible of the underground structure of the area surveyed.

That picture is obtained by a sort of three-dimensional geometry. If

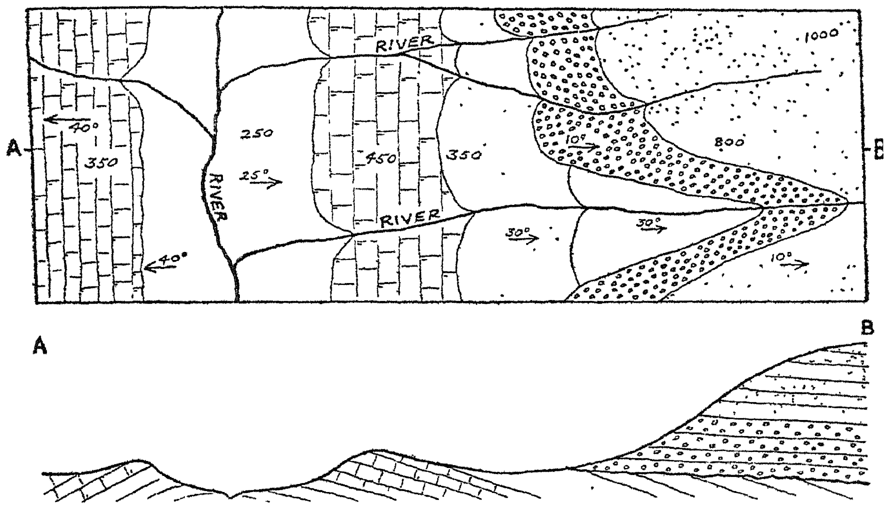

FIG. 25 A SIMPLE GEOLOGICAL MAP AND SECTION

The map shows the surface outcrop of a set of beds folded into a simple anticline, after being subjected to prolonged denudation and the establishment of a river-system. An unconformable series of beds outcrops to the east.

a bed of rock is, for example, found to be dipping in a certain direction a a measured angle, it is assumed that dip continues for some way. If tw exposures a mile apart of what is found to be the same rock show tha the dips are towards one another, then it can usually be assumed that th stratum has been folded into a syncline and that the two exposure represent the eroded edges of the fold. To help in this analysis section are drawn along various lines on the map and gradually a more or les complete picture is developed. Sometimes it is found that a furthe search is needed in the field to fill in doubtful patches, but the section and picture already built up will often serve to indicate where a thoroug search for confirmatory evidence should be sought.

Of course, in most districts the position is not so easy, the rocks hav been much folded and faulted, and very careful field-work and experienc

in reconstruction is needed to obtain a true picture. This work is never complete, and even in a country like England, where geological mapping has been going on for well over a century, new data is always being accumulated. Especially, of course, is this the case when, for some reason or another, deep borings are made. These are very expensive and are not put down without the promise of some tangible reward, that is for mining purposes.

The war-time demand for petroleum, and the need to save shipping space, led to the Government subsidy of exploration for natural oil in Britain. During war-time there is always money available for such work —which private enterprise cannot afford in peace-time, unless there is a strong likelihood of success. Many hundreds of bores were put down in various parts of England, principally in the East Midlands. Oil was found in workable quantity in Nottinghamshire, but from the purely scientific standpoint a great deal more was obtained, namely, valuable information about the deep underground structure of the area in question. Inferences had already been made about the extension eastwards of the older rocks of England under the Mesozoic and more recent rocks of East Anglia. The new data obtained by the borings has confirmed and enlarged these inferences, and we now know that the Carboniferous Beds of Nottingham and Derby extend under the Lincolnshire Jurassics.

But such exploration of the crust by boring is not often done, it is very expensive, so that other methods have been devised to help fill in the precise details of the geologist's picture. The farther away from the outcrops we get on that picture, the more vague become the details. Today there are, however, other methods of investigation at hand to help, the methods of the geophysicist, which, as his name implies, is a scientist who applies knowledge to the investigation of the earth.

Geophysical Methods

The basic principle on which the geophysicist works is that different rocks have different physical properties, different densities, varying hardness, conductivites as regards vibrations, and so on. Instruments have been devised to measure these things. One such instrument measures the force of gravity with which most of us are familiar. We attribute the downward pull of objects to the attraction of the earth as a whole, but in so doing we often fail to realize that every part of the earth contributes its part to the total force exerted, and that part is proportional to the mass of that part and also depends on the distance away it is. Rocks that are more dense than others exert a greater attraction than lighter ones. Gravity-meters can detect differences in the force exerted and therefore give a clue to the nature of rock masses deep below the surface.

These gravity-meters are very sensitive, being capable of measuring changes in gravitational attraction of less than one part in 10 million.

This means that if a reading were taken over a bath of water, and another reading taken after only a few drops of water had been added there would be a difference in the readings. These meters depend for their action on the principle that a twisted or bent fine metal wire will, if suitably loaded, show a variation of the twisting or bending as the attractive force varies. Gravity determinations of this sort are much used in searching for natural oil. This is often found associated with limestone anticlines, and limestone is heavier than many other rocks, so that these anticlinal structures can be detected even when they lie hidden under other surface beds.

A second method which the geophysicist uses is to create artificial earthquakes on a very small scale. We have already noted that study of real earthquake vibrations enable us to infer something of the internal nature of the earth, because vibrations travel at varying speeds in varying materials, travelling faster through denser rocks than through lighter rocks. The artificial shocks are produced by exploding charges of dynamite and the vibrations are recorded on seismometers.

Hard, dense rocks, such as limestone, for example, also reflect such vibrations better than do softer less dense ones, and this fact is also made use of in this sort of crustal exploration. The seismometer then records the initial shock, which may be quite close at hand, and then later there comes the reflected or echo shock from the harder band underlying the softer rocks above it. The speed of the vibrations through the softer rocks being already determined, it is easy to calculate the depth of the harder rock when the time intervals between the shock and its echo is known. There are, of course, many complications and difficulties in the method owing to the complexity of the strata in the crust, but so useful is it in detecting the limestone anticlinal folds that often contain oil, that many leading petroleum companies invariably make such surveys before boring.

Exploration of the Oceans

Our knowledge of the ocean floor has considerably advanced in recent years due again to the devisal of new instruments, in this case adapted from the submarine detecting apparatus used in the war against submarines. Charting of the sea-floors, that is, the measuring of water depths, was done in the past by the use of the log-line. This was a slow and tedious process and was only effective in shallow water. Today, echo-sounding apparatus is used and in this way much of the ocean floor is being mapped, and it is possible to draw contoured maps of it as we do of the land surface of the globe. Sound travels through water at a velocity that depends on the temperature and density of the water and, therefore, can be detected by the use of suitable instruments. This was made use of in submarine detectors, which were instruments sensitive enough to pick up the noise of engines, etc., at a considerable distance

from the source of the noise. Submarine commanders soon found an answer to this method of detection; they lay on the bottom with their engines shut off whenever they suspected enemy craft in their vicinity. This led to a variation of the method, the detecting vessel made the noise. This was then reflected back from any solid object in the neighbourhood, if such were present.

It is this echo method that is now being used for oceanographical surveys. A survey ship sails along a given course and emits sound with a short wave-length—this gives better results—vertically downwards, the ocean floor reflects an echo back and this is recorded on the sensitive instrument aboard. The necessary calculations are made automatically, several readings a second can be taken, a continuous record can be made, and the result is a complete vertical section of the floor beneath the ship's course. A given area of ocean is tracked and cross-tracked, and in this way a map of the floor can be drawn. This method, too, is applicable for the deep as well as for more shallow regions of the oceans.

Exploring the Upper Air

Our knowledge of the atmosphere has advanced very considerably in recent years thanks mainly to the development in the aeroplane and the need for more accurate weather forecasts for aerial flight both in peace and war. Until the advent of high-flying aircraft equipped with recording apparatus, our knowledge of the atmosphere was confined to ground level or a few hundreds of feet above it. It was soon realized that this did not give sufficient information either of the atmosphere as a whole or for accurate weather forecasts.

During the 1914–1918 war the two Swedish meteorologists, Vilhelm and Jakob Bjerknes, first carried out systematic upper-air observations and proved the existence of the polar front and of separate air-masses. Between the two world wars the technique of air-mass analysis was developed and was standard practice in such countries as the United States.

The development of radio was a means by which the highest levels of the atmosphere were investigated for it was not until world radio became possible that the discovery of the reflective layer known as the Heaviside Layer was made. Another instrument now used in upper-air investigation is the radio-sonde, a small balloon, to which is attached instruments which automatically record atmospheric temperatures, pressure and humidity. The balloon is let off and allowed to rise. As the balloon ascends into the atmosphere the pressure outside it decreases until a point is reached at which the pressure inside is sufficient to burst it—this bursting-point is determined by the original pressure within the balloon and can be adjusted so that the balloon bursts at a given height. The instruments then float back to earth on a small parachute which

forms part of the whole apparatus. Many other instruments used in meteorology are still on the secret list, for example, the one that is capable of detecting the presence of thunder-storms several hundred miles distant. Thousands of our airmen owe their lives to the increased accuracy in forecasting which has been made possible by such instruments.

The highest levels of the atmosphere—the ionosphere—were beyond experimental observation until the development of radio had progressed sufficiently for signals to be sent to the Antipodes. It was the fact that signals sent out from Britain, let us say, could be heard in Australia, that led scientists to postulate the existence of the ionized shell at the base of which lies the reflective layer known as the Heaviside layer.

The development of long-distance heavy aeroplanes has made other earth knowledge possible, as for instance the re-plotting of the North Magnetic Pole recently carried out by a Lancaster bomber of the Royal Air Force. Journeys to and through the Arctic regions were difficult and lengthy, especially if much scientific apparatus had to be carried, when those journeys had to be made by sea and land, but flying makes things easier. In 1831 James Ross, the Arctic explorer, gave the position of the North Magnetic Pole as being near Boothia Felix, in the far north of Canada. In the summer of 1945 the Lancaster *Aries*, equipped with suitable apparatus, made a cruise over Arctic regions and found that, as expected, the site had changed and was now in the Sverdrup Islands, some 200–300 miles to the north-west of the old site and about 1,500 miles from the geographical North Pole. This site is about 75 miles from the point calculated for it by the Astronomer-Royal, Sir Harold Spencer Jones, but that discrepancy may be due to the fact that the observations were made from a moving aeroplane.

One of the differences between the sciences which deal with the earth and those of physics, or chemistry, is that there is very little power of prediction in the former group. For example, our knowledge of the causes and nature of earthquake shocks is now fairly good, but it is as yet impossible to foretell accurately when and where a shock will occur. Since, however, we believe that such shocks are due to changes in tension and density in the deeper levels of the crust, it may well be that improvements in the making of recording and measuring instruments will enable us to determine when such changes occur, especially in those regions which are subject to earthquakes. The result would be a great saving of life and property.

BIBLIOGRAPHY

ONE of the drawbacks which a student may meet in pursuing his reading is that of not knowing which of the many books available are simplest, or most accurate, or controversial, and so on. The following list of books is given—with notes—because they are all ones with which the present author is acquainted. Others would, doubtless, compile a very different list. Apart from one or two standard works, most of the books listed are published cheaply, no slight consideration at any time.

GENERAL GEOLOGICAL:

Teach Yourself Geology, by H. Raistrick. (Published by the English Universities Press.) This is a recent and very readable introduction to Geology and deals with such subjects as denudation, deposition, geological history and earth-movements in an interesting and accurate manner.

Text-book of Geology, by Lake and Rastall. (Published by Arnold.) This is a standard text-book. Very useful for reference in all aspects of Geology.

The Earth, its Nature and History, by Edward Greenly. (Published by Watts & Co.) Short and concise general account of our planet.

Principles of Physical Geology, by Arthur Holmes. (Published by Nelson). Latest and best book on the subject.

AGE OF EARTH:

The Age of the Earth, by Professor Arthur Holmes. (Benn's Sixpenny Library.) Out of print, but may be obtainable second-hand. Interesting and accurate, although rather small.

ASTRONOMICAL ASPECTS:

Astronomy, by Ball. (Published by Cassell.) Old (1910), and out of print, but can be consulted in libraries. Still very readable but not up to date.

The Stars in their Courses, by Sir James Jeans. (Pelican Books.)

From Atoms to Stars, by Martin Davidson, D.Sc., F.R.A.S. (Hutchinson Scientific and Technical Publications, 1946.) Well written and reliable guide to modern astronomy.

ATMOSPHERE:

The Weather, by George Kimble and Raymond Bush. (Pelican Books.) Interesting and readable account of British weather with much information on atmosphere in general. Good cloud photographs.

Weather Study, by Brunt. (Nelson.) Mainly concerned with the physical characteristics of the atmosphere and the basic meteorological principles. Accurate and interesting.

OCEANOGRAPHY:

The Floor of the Ocean, by R. A. Daly. (Oxford University Press.) The latest work on this subject, embodying much new information.

SOILS:

Good Soil, by Brade Birks. (English Universities Press.) "Teach Yourself Series". A fascinating book. Nothing like it published in England before.

GLOSSARY

ALLUVIUM.—Name given to fine-grained material deposited by rivers, either at their mouths or over their flood-plain.

APOGEE.—The moon is said to be in apogee when it is at its maximum distance from the earth.

ATOM.—The smallest portion or particle of an element that can take part in a chemical reaction. Once believed to be the ultimate particle of matter.

AURORA BOREALIS (Northern Lights).—Display of coloured lights and glows, mainly red and green, visible in Arctic and Antarctic regions. It is almost certainly caused by streams of electrified particles from the sun; it is most prominent when there are large sun-spots to be seen.

CELESTIAL EQUATOR.—The great circle formed by a plane which includes the earth's centre and its equator extended out into the celestial sphere.

CELESTIAL SPHERE.—Sphere of indefinite extent containing the visible stars.

CENTRIFUGAL FORCE.—The outward force of a body revolving in a circular movement around a central point.

CRYSTAL.—A substance—element or compound—occurring in solid form in a definite geometrical form and structure enclosed by symmetrically arranged plane faces.

DENUDATION.—Combined effects of erosion and weathering (*q.v.*)

EQUINOX.—Moment at which sun apparently crosses the celestial equator. Generally understood to be the times of year when the sun, at noon, is vertically above the Equator and so results in equal day and night. This occurs about March 21 (Vernal Equinox) and September 23 (Autumnal Equinox).

EROSION.—Destruction of land by agents such as glaciers, streams and winds that break up and remove rock débris.

FRAUNHOFER LINES.—Dark lines in the continuous spectrum of the sun, caused by the absorption of some of the white light from hotter inner regions of sun, by elements contained in the cooler outer layer or chromosphere.

GALAXY. (Island Universe).—Huge cluster of stars, separated by extremely great distances from other clusters. The Solar System, together with all stars visible in sky, form our own galaxy. Other galaxies are so far distant that they appear as nebulae and we cannot detect individual stars in them. Average diameter $7{\cdot}6 \times 10^{17}$ miles.

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